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Information Visualization

The State of the Art for Maritime Domain Awareness

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Contract Number: W7707-053019/001/HAL

Contract Scientific Authority: A.-L. S. Lapinski (902) 426-3100 ext 180

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Defence R&D Canada – Atlantic

Contract Report
DRDC Atlantic CR 2006-122
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Canada

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Abstract

This Final Report provides an analysis of the current state of the art for Information Visualization, as it applies to Maritime Intelligence, Surveillance, and Reconnaissance (MISR). It comprises a Literature Survey, an Annotated Bibliography, a Product Review, and recommendations for further research. The Literature Survey focuses on visualization algorithms and strategies, human factors for visualization, and emerging display hardware, and includes a list of foundational books and papers, an introduction to major research leaders, and a list of current pressing research questions. The Annotated Bibliography provides about 240 references to texts, conferences, journals, and institutional websites. The Product Review gives one-page descriptions of sixty eight MISR-related visualization products, ranging from public-domain code for a specific visualization task, to commercial multipurpose toolkits. The report concludes by recommending specific research tasks for visualizing sensor coverage and ignorance, ship tracks in time and space, ship tracks versus "normal" tracks, and attribute data such as cargo and crew.

Résumé

Le présent rapport final constitue une analyse du nec plus ultra actuel en matière de visualisation de l'information dans le domaine du renseignement, de la reconnaissance et de la surveillance maritimes (MISR). Il comprend une étude de la documentation, une bibliographie annotée, un examen des produits et des recommandations en vue d'études plus poussées. L'étude de la documentation porte essentiellement sur les algorithmes et les stratégies de visualisation, les facteurs humains liés à la visualisation et le nouveau matériel d'affichage. Elle offre une liste d'ouvrages et d'articles généraux, une introduction aux principaux chefs de file en recherche et une liste des questions actuelles et pressantes en matière de recherche. La bibliographie annotée comporte environ 240 renvois à des textes, conférences, revues et sites Web institutionnels. L'examen des produits fournit une description d'une page de soixante-huit produits de visualisation liés à MISR. Il peut s'agir de produits servant au codage du domaine public en vue d'une tâche de visualisation particulière jusqu'à des trousses d'outils commerciales utilisées à des fins diverses. Le rapport se termine par des recommandations concernant des tâches précises en matière de recherche : visualisation de la couverture de capteurs et exclusion des données reçues; suivi de navires dans le temps et l'espace; suivi de navires et suivi « normal »; données de caractéristiques comme celles liées au fret et à l'équipage.

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Executive summary

Background

On April 1, 2005, DRDC started a new applied research project in the Maritime Intelligence, Surveillance, and Reconnaissance (MISR) Thrust: Project 11he - Information visualization and management for enhanced domain awareness in maritime security. The goal of the project is to enhance the "maritime picture" through improved quality of information and novel, adaptive ways of visualization.

As part of this R&D project, the state-of-the-art of information visualization needed to be established. A study was therefore undertaken, which included a literature survey and a product review with an emphasis on maritime domain awareness (MDA) and MISR.

The study focused on technologies and research relevant to space-time visualization of moving objects, including uncertainty; visualizing abstract information attached to moving objects, such as cargo pedigrees, including uncertainty; visualizing what is unknown, in the information spaces; visualization strategies for Domain Awareness; analytical tools for quantifying, predicting, and preventing information overload as a function of visualization con-ops; and visualization strategies for preventing information overload.

Results

The results of the literature survey include recommendations on foundational documents, information on research leaders and document recommendations on topics of interest. The product review portion of the report discusses over 50 products organized into categories such as 2-D displays, knowledge visualization, linking knowledge to spatial data, etc. In addition to this report, an Endnote® database of useful documents was created with comments from the authors, quality assessments of some documents, keywords, and links. The hardcopy version of this database is located in the Annotated Bibliography section of the report.

Significance

This report provides foundation material for the development and evaluation of visualization tools to support operators in the Marine Security Operations Centres. Selected concepts for visualization aids will be implemented on a maritime domain awareness research testbed, a planned environment for the evaluation of emerging ideas and tools for operational system development. This report and the planned exploration of possible visualization tools will provide useful insights for those involved in establishing or improving the recognized maritime picture (RMP) and MDA, as well as those involved in MISR.

Future Plans

The products and literature reported will be reviewed and applied to the goals of the project. For example, visualizing uncertainty is an area of particular interest to the project. Products and literature applicable to that area can be used in the research.

Davenport, M. and Risley, C. 2006. Information Visualization: The State of the Art for Maritime Domain Awareness. DRDC Atlantic CR 2006-122, Defence R&D Canada − Atlantic.

Sommaire

Contexte

Le 1er avril 2005, RDDC a entrepris un nouveau projet de recherche appliquée dans le domaine du renseignement, de la reconnaissance et de la surveillance maritimes (MISR), soit le projet 11he – Visualisation et gestion de l'information, et ce afin d'accroître la sensibilisation au domaine de la sécurité maritime. L'objectif de ce projet est d'améliorer l'« image maritime », en améliorant la qualité de l'information et en ayant recours à des méthodes de visualisation novatrices et adaptatives.

Dans le cadre de ce projet de R et D, il fallait définir le nec plus ultra en matière de visualisation de l'information. C'est ainsi qu'on a mené une étude comprenant elle-même une étude de la documentation et un examen des produits, en portant une attention particulière à la sensibilisation au domaine maritime (MDA) et à MISR.

L'étude a traité essentiellement des technologies et des recherches propres à la visualisation dans le temps et l'espace d'objets en mouvement, y compris l'incertitude; à la visualisation d'information abstraite accompagnant des objets en mouvement, comme la provenance du fret, y compris l'incertitude; à la visualisation de ce qui est inconnu dans les espaces d'information; à la visualisation de stratégies en vue de la sensibilisation au domaine; aux outils d'analyse en vue de quantifier, prédire et prévenir la surabondance d'information comme fonction des concepts d'opération liés à la visualisation; aux stratégies de visualisation en vue de prévenir la surabondance d'information.

Résultats

Les résultats de l'étude de la documentation donnent lieu à des recommandations concernant les documents généraux et à de l'information relative aux chefs de file en matière de recherche, et documentent des recommandations concernant des sujets d'intérêt. L'examen des produits fait état de plus de 50 produits organisés en catégories, comme les affichages 2D, la visualisation de la connaissance ainsi que l'établissement de liens entre la connaissance et les données spatiales. Outre ce rapport, une base de données Endnote® des documents utiles a été créée grâce aux commentaires émis par les auteurs et aux évaluations de la qualité de certains documents, mots-clés et liens. La version sur papier de cette base de données se trouve à la section « Annotated Bibliography » du rapport.

Pertinence

Le présent rapport sert d'outil de base à l'élaboration et à l'évaluation d'outils de visualisation à l'appui des opérateurs des centres d'opérations de la sécurité maritime. Des concepts choisis liés aux aides à la visualisation seront mis en œuvre au banc de recherche en matière de sensibilisation au domaine maritime, soit un environnement planifié permettant d'évaluer les idées nouvelles et les nouveaux outils concernant le développement de systèmes opérationnels. Le présent rapport et l'exploration prévue des outils de visualisation possibles donneront un aperçu utile aux personnes qui établissent ou améliorent l'image maritime reconnue (RMP) et la MDA, ainsi qu'à celles qui participent à MISR.

Plans futurs

Les produits et la documentation dont il est question seront examinés et appliqués aux objectifs du projet. Ainsi, par exemple, la visualisation de l'incertitude constitue un aspect particulièrement intéressant dans le cadre du projet. Les produits et la documentation concernant cet aspect peuvent servir aux travaux de recherche.

Davenport, M. and Risley, C. 2006. Information Visualization: The State of the Art for Maritime Domain Awareness. DRDC Atlantic CR 2006-122, Defence R&D Canada − Atlantic.

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1 Introduction

This paper is the final report of a study to establish the state of the art in the field of Information Visualization, as it applies to Maritime Intelligence, Surveillance, and Reconnaissance (MISR). By "information visualization" we mean:

> "The use of computer-supported, interactive, visual representations of non-physically based abstract data to amplify cognition."(Card et al. 1999) pg 7

The study was split into two tasks: a literature survey (Section 2) and a product review (Section 3), as sketched in Figure 1.

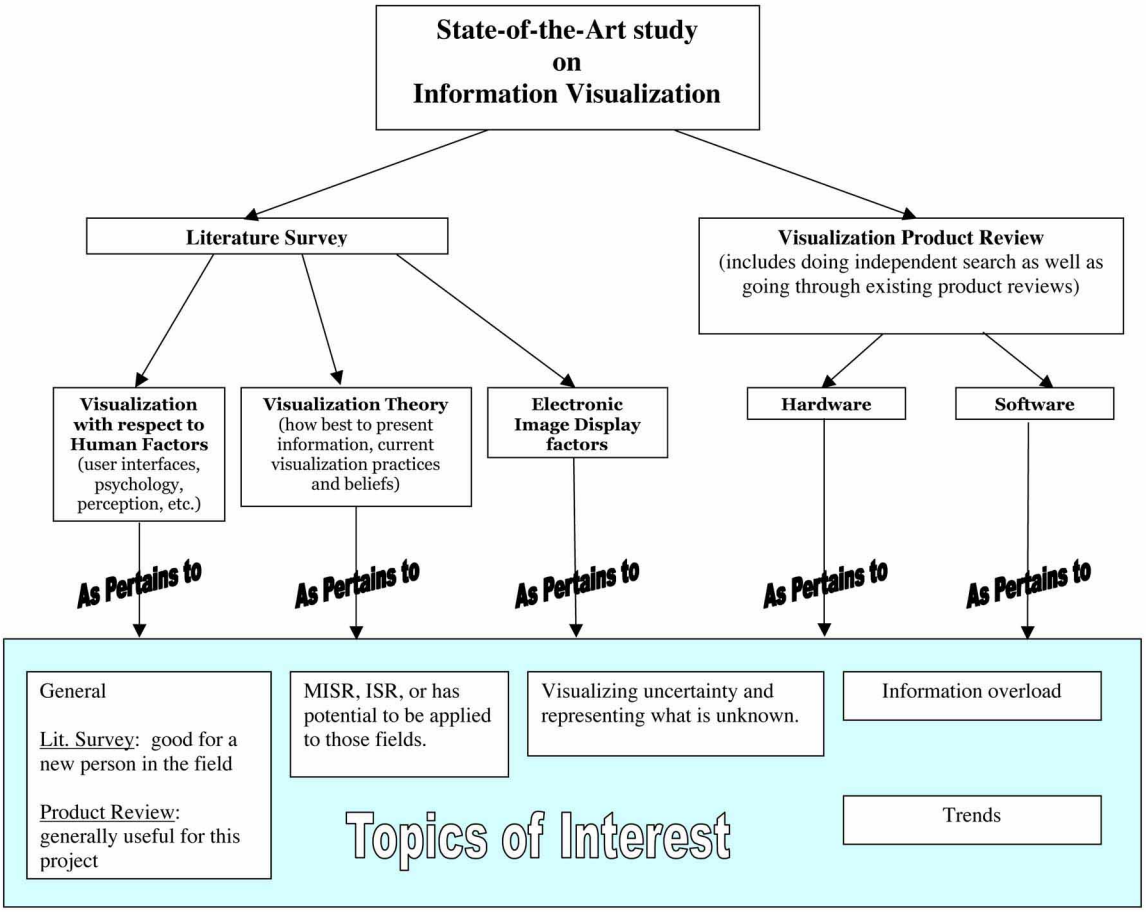


Figure 1. *Breakdown of the Study and Topics of Interest*
This figure was used in the Request for Proposal (PWGSC 2005) to illustrate which topics to focus on in both the literature survey and the product review portions of the contract.

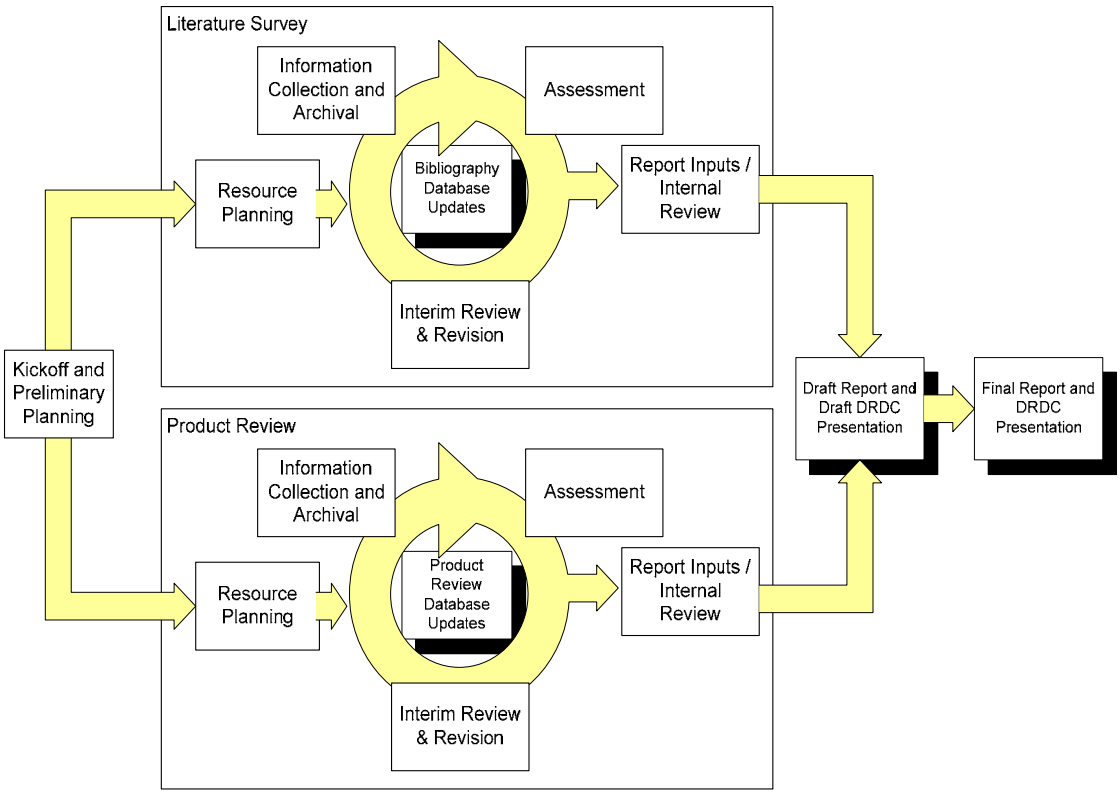


Figure 2. *General Approach for the Product Review and Literature Survey*

The product review started several weeks into the project. The first task was to identify a more detailed set of areas that required further investigation. This refined list of categories served as the starting table of contents, and was also used to structure the search process.

Figure 2 summarizes our general approach to the study. Both the literature survey and the product review were iterative processes of seeking information, reading and understanding it, documenting it, and then searching for more information.

1.1 Scope

To be valuable, this study must not try to address the entire fields of human factors analysis and information visualization (which are anyway far too large to be fully explored in a study of this size) but must rather focus on those aspects of those fields that are most likely to be valuable to MISR. At the beginning of the study we intentionally cast the net quite wide in search of technologies that might, unexpectedly, be very relevant to MISR.

We therefore focused on the following topics:

- Space-time visualization of moving objects, including uncertainty;

- Visualization of abstract information attached to moving objects, such as cargo pedigrees, including visualization of uncertainty in that information;

- Visualization of what is unknown, in the above information spaces;

- Visualization for Domain Awareness, by which we mean holistic perception of a wide area, over an extended time;

- Strategies for preventing visualization information overload, including strategies and analytical tools for quantifying and predicting information visualization loads.

We consciously avoided being distracted by topics such as the following:

- GIS research and tools such as GCCS, Google Earth and ESRI ArcGIS. Reason: these tools, while relevant, and usually considered to be outside the current "information visualization" research thrusts;

- Visualization, for littoral operations, of nearby land. Reason: visualization of land is a huge field and would distract us from MISR research;

- Real-time battlespace visualizations, except where the technologies are equally applicable to Maritime ISR. Reason: ISR is traditionally concerned with assembling the "bigger picture" in both time and space, than that developed for real-time battlespace visualizations.

- Visualizations for Maritime mission rehearsals (e.g. immersive environments). Reason: MISR generally requires a more abstract, less literal visualization of the area of interest.

- Visualization strategies for Communication Security (COMSEC) applications, such as detecting hackers or signal jamming. Reason: this element of surveillance is generally managed by a different government agency that traditional MISR.

This document contains many internet links and addresses that were correct at the time of the study. We expect the reliability of those links to steadily degrade over time, in which cases readers will need to rely on search engines to establish more up-to-date links.

2 Literature Survey

This section reviews the Literature Survey that was done under this contract. The discussion includes the following:

- a review of the objectives and scope of the Literature Survey (Section 2.1)
- a summary of the methodology used (Section 2.2), and
- a list of foundational reference books and papers (Section 2.3.1)
- a list of some important research leaders (Section 2.3.2)
- a discussion of the pressing issues being faced by the research community (Section 2.3.3)
- a cross-reference between the topics of particular interest, and the papers in the annotated bibliography (Sections 2.4 and 2.5)

The primary deliverable from this literature survey is the annotated bibliography at the end of the Document.

2.1 Objectives

The purpose of this Literature Survey is to provide a foundation for the ARMADA research to develop improved methods for visualizing the maritime picture [ref SOW par 4]. Specifically it will:

- establish a baseline description of what the current "state of the art" in visualization is;
- identify seminal texts and documents for information visualization as it pertains to the Recognized Maritime Picture;
- identify key researchers in the field;
- give a high-level description of the pressing challenges and directions of current research
- address specific topics of interest

2.1.1 Literature Survey Scope

The scope of this Literature Survey is described in the contractual Statement of Work (PWGSC 2005) as follows:

- focus on novel, adaptive ways of visualizing maritime intelligence, surveillance, and reconnaissance (MISR/ISR) information for the enhancement of the "maritime picture."

- include a review of the related Human Factors literature, including texts on user interface design principles, psychological studies, and perception research

- include a review of visualization theory including current visualization practices and beliefs

2.1.2 Topics of Interest

Some topics of interest are laid out in the Statement of Work (SOW), some were raised during progress review meetings, and some have been added in response to the SOW request for the contractor to "express educated opinions." Here are the main topics of interest that we pursued:

- **Space-time visualization** of moving objects (e.g. ships), including: position as a function of time, **uncertainty**, historical movements, and deviations from the norm;

- Visualizing **attribute information** on moving objects such as: ship class, cargo pedigree, and confidence levels in the attributes;

- Visualizing **what is unknown** in the above information spaces such as: displaying "no targets" differently than "no data";

- Visualization strategies for Domain Awareness: which primarily means achieving a **holistic perception** of a wide area, over an extended time

- Human Factors principles and visualization strategies to predict, identify, and if possible prevent **information overload**

- **Human factors** principles to provide guidance in new visualization developments

- **Measures of Effectiveness** (MOEs) that can be used to evaluate the quality of research results.

2.1.3 Topics Outside the Scope

The following list exemplifies topics that are not covered within this study:

- Visualization, for littoral maritime operations, of nearby land: although this is marginally relevant to the Navy, it is not traditionally part of the Recognized Maritime Picture (RMP), and would seriously de-focus the analysis;

- Real-time and realistic battlespace visualizations for mission rehearsal (e.g. immersive environments). These would only be addressed if our analysis suggested that they could add value to the RMP or Maritime ISR:

- Visualization strategies for Communication Security (COMSEC) applications, such as detecting hackers or signal jamming. COMSEC is currently not included in the RMP, although it could in principle be included in the future.

2.2 Methodology

The Literature Survey resembles in many ways the standard intelligence-gathering and analysis activities used in the preparation of the Maritime Picture, and thus followed the same standard iterative methodology:

- **data gathering:** we explored the internet, bookstores, libraries, and bibliographies for publications that addressed the topics of interest
- **data filing:** we used EndNote (Thomson 2005) software to file document titles and summarize relevant information in a searchable database
- **information interpretation:** we used the text of this document to build a structured model of the information that was filed
- **gap analysis:** as data gaps were identified, we iterated the above steps to fill in the missing information.

Figure 3 illustrates what Thomas and Cook call the "sense-making loop" that is used by analysts in a wide variety of fields, including maritime surveillance, and that equally well describes the methodology used in this report.

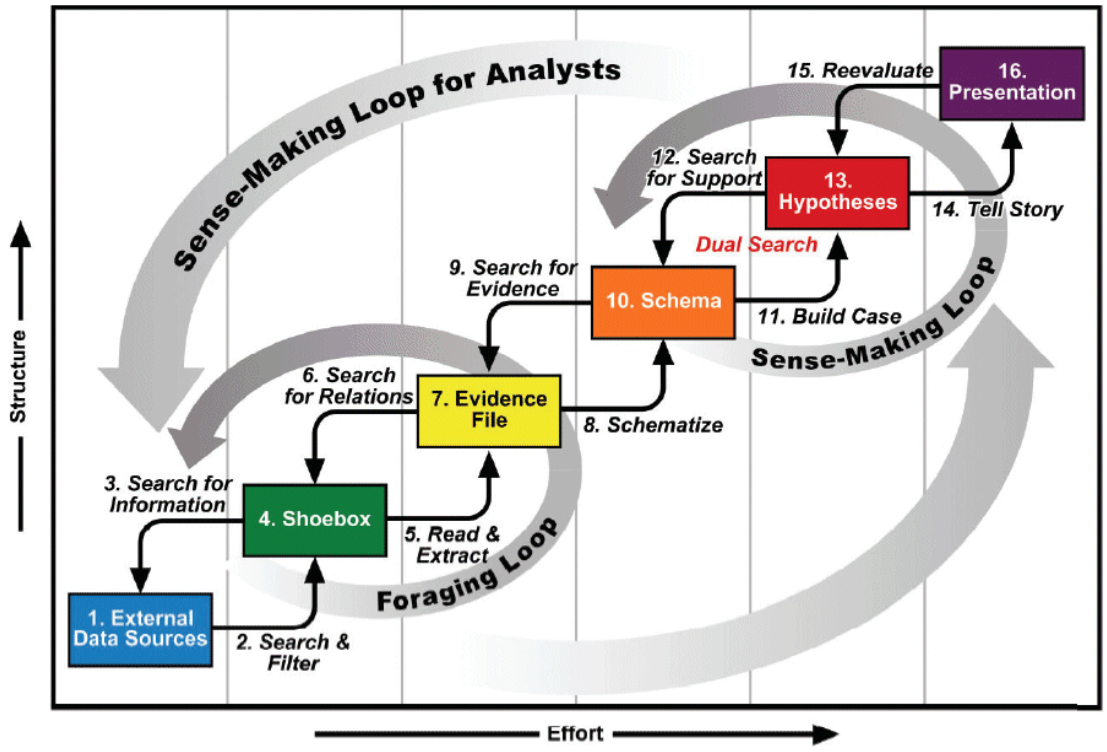


Figure 3. *The Sense-Making Process*

The Methodology used to produce this report was very similar to the process described here by Pirolli and Card (Pirolli et al. 2005). Analysis is iterative, and includes a "foraging loop" and a "sense-making" loop.

2.2.1 Bibliography Software

We used EndNote software (Thomson 2005) to provide some automation of the "foraging loop" in Figure 3, as follows:

- our corporate librarian undertook activities (2) and (3) in the figure, searching for information (primarily via the Internet), filtering it for relevance, and "shoeboxing" the following information into EndNote:
    - all citation information (authors, title, dates, publication information)
    - the author's abstract, whether explicitly labelled as such or implicitly extracted from the introduction, for example, and
    - a web link to the document or abstract

- the project scientist used the shoebox information to build the "Evidence File" shown in the diagram in Figure 3, as follows:
    - he read the citations to determine whether and how they were relevant
    - he accordingly added "KeyWord" annotations (see Section 2.2.4) and "Notes" to the EndNote records, thus upgrading them from Shoeboxes to Evidence Files (activity 5 in the diagram). The keywords and Notes are printed in the Annotated Bibliography
    - as the Evidence Files grew, he was able to adjust the schema from that which was originally proposed, to fit the growing body of evidence. (activity 8 in the diagram)
    - as the schema emerged, he became aware of gaps in the records, and searched the database and external data sources to fill those gaps (activity 9 in the diagram).
- with the Evidence File and Schema in place, the Project Scientist completed the sense-making loop (activities 11 to 15) using only the document editor, and inserting references to the bibliography as required.

2.2.2 Search Tools

The primary search tools that we used were:

- public search engines such as Google (Google 2006b), Google Scholar (Google 2006a), and CiteSeer (CiteSeer 2006)
- search engines built into archives, such as the search engine at IEEE (ieee 2006a)
- citation lists, either in text form in books and journal articles, or in electronic form at websites such as CiteSeer or Google Scholar

When a subject-word search would find a title and perhaps an abstract on a restricted pay-per-article site, we would search for the title and author name on the open web. When we found it there (and we usually did find it) only the free version is included in the bibliography.

2.2.3 Review Criteria and Approach

We evaluated some key articles and books against the following criteria, which are based on the IGARSS review criteria [ref http://www.usra.edu/esse/jesse/jesse2000/igarss2000.doc]:

- **Scientific Quality:** accuracy, theoretical basis, amount of evidence
- **Scientific Context:** the number of references to related work
- **Significance:** originality, applicability to MISR, potential impact, vision

- **Quality of Presentation:** clarity, brevity, illustrations

- **Qualifications:** seniority and credibility of the authors and their institutions

Numerical values were assigned subjectively, but approximately in accordance with the criteria laid out in Table 1. We then modified the Reference types in EndNote to include a "Quality" field, and for key documents we entered five criteria as a single string such as "2 2 0 2 1" which means "high quality research with lots of references, well presented, and by a fairly well qualified scientist, but not very relevant to MISR." For fields where we are not able to assign a quality value, we use a "?" as a place holder.

Table 1. *Review Criteria*

Scientific Quality	
0	Advertising and/or presenting unsubstantiated claims or marketing
1	Reasonable technical approach, partially validated, and/or review paper
2	Journal Paper, extensive theoretical foundations, well validated

References	
0	Little or no reference to the scientific literature
1	Technical Paper with average number of references
2	Review Paper with extensive references

Significance	
0	Not novel; previously published elsewhere; irrelevant for Maritime ISR
1	Contains a few good ideas, at least one important insight or technology, and/or reviews other papers
2	Seminal paper establishing or reviewing a major technology

Quality of Presentation	
0	Poor grammar, difficult to read, few images, confusing
1	Typical conference paper quality
2	Notably clear, easy to scan, well illustrated, good information density

Qualifications	
0	Unidentified or junior author or institutional source
1	Senior researcher who is new to this field
2	Recognized expert in the field

2.2.4 EndNote Keywords

As the literature survey progressed, it became clear that some of the topics in Section 2.1.2 were very heavily represented (for example the analysis of tabular data and attribute information) and others (such as the visualization of what is not known) are almost completely missing from the literature. We used the Keywords shown in Table 2 to roughly categorize the EndNote records.

2.2.5 Resulting Bibliography

The resulting Annotated Bibliography includes about 240 references. These can be broken down into classes approximately as follows:

- by reference type :
    - 36 books
    - 37 articles from technical journals
    - 98 conference papers
    - 12 descriptions of ongoing visualization conferences and journals
    - 14 corporate brochures
    - 13 home page references for Research Leaders
    - 21 articles published on line without association to a journal or conference
    - 2 theses
    - 2 Wiki pages
- by date:
    - citations reach back to 1980, and are heavily centered on the period from 2003-2006, as shown in Figure 4.
- by content :
    - the breakdown by content is discussed in Section 2.3

Table 2. *Keywords Used to Mark Up the Citations*

Keyword	Meaning
Architecture	Article addresses architectures for visualization systems
Canadian	Article is about or by Canadian people or institutions
Centre of Excellence	This is a home page for a centre of excellence in visualization
Collaboration	Article describes tools, architectures, or CONOPs for collaborative visualization
Conference Stream	This is a home page for a visualization conference that occurs regularly (only one reference is given, as previous years can be found via links)
Coverage Maps	Article describes ways to visualize sensor coverage over a spatial area
Defence	Article describes a defence application such as MISR
Display Hardware	Article discusses capabilities or advantages of display hardware configurations
Graphics	Article subject is better described as “graphics” than “visualization”
Haptic	Article addresses Haptic (touch) feedback
Human Factors	Article addresses topics normally considered part of “human factors” research
Information Landscapes	Article focuses specifically on visualizing abstract information as a landscape
Journal Stream	This is a home page for a regularly-published journal on Visualization research
Low Value	Flags articles that are not very useful for MISR (most have been removed)
METOC	Article describes Meteorology or Oceanography visualizations
MOE	Article discusses Measures of Effectiveness
Not MISR	The topic does not obviously apply to MISR visualization
Overload	Article addresses the problem of information overload in visualization
Philosophical	Article focuses on broad concepts and ideas rather than implementation issues
Requirements	Article discusses what gaps remain in our visualization capabilities
Research Leader	This is a home page for a person who is a leader in the field of Visualization
Review Article	Article or book covers many different visualization topics, or presents an overview and thorough bibliography of one specific field.
Semantic Web	Article looks a ways to visualize textual data or the semantic web
Software Resource	Article describes a specific solution to a specific problem. The value of the article is that, if you ever had that specific problem, you could find a solution here.
Tabular Data	Article is visualizing data that could be enumerated in tables – that is: arrays of numerical values rather than continuous fields of data
Textbook	Provides a comprehensive treatment of a broad domain within visualization
Time and Space	Article describes strategies for visualizing [x,y,z,t] space
Uncertainty	Article describes ways to visualize uncertainty in data
Unknown	Article discusses the need for, or a technique to, visualize what is unknown
Visual Analytics	Using visualization space as a workspace rather than just passively observing it.

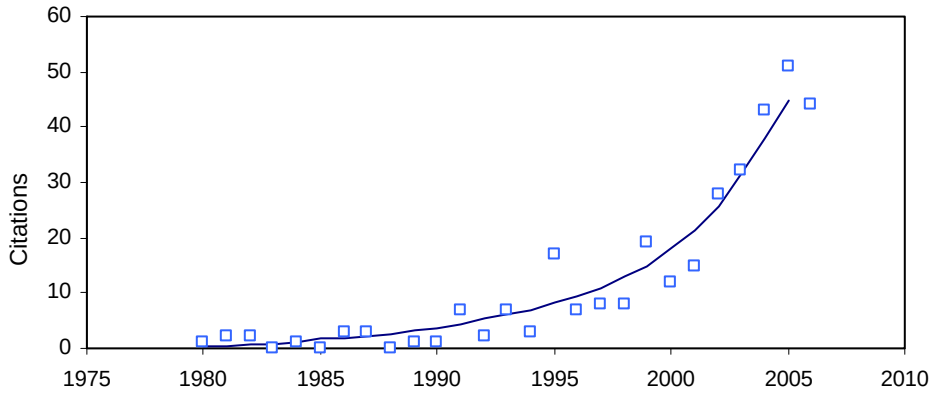


Figure 4. *Citations by Year*
This chart shows the distribution of citations in the Annotated Bibliography as a function of age. The squares show the number of citations examined, all of which are in the EndNote database, but not all of which are in the printed bibliography. The solid line is hand-drawn to emphasize the trend.

2.3 Current State of the Art

This section gives a high level summary of the conclusions that can be drawn from the literature survey. Section 2.3.1 introduces key documents and books that establish the foundation of the twin disciplines of Human Factors and Scientific Visualization, and Section 2.3.2 lists the scientific leaders in those disciplines. Section 2.3.3 then summarizes the current focus of attention of the two research communities, with reference to representative papers as appropriate.

2.3.1 Foundational Documents

Chen (Chen 2004a) has shown that the discipline of computer-aided scientific visualization had its infancy in the 1990s, so it is not surprising that even five year old books and documents in Visualization are already looking dated. The aging process is not quite so extreme in Human Factors. Fortunately there are excellent books in both fields that are very up to date. We recommend the following:

2.3.1.1 Human Factors:

There is broad agreement that the pre-eminent text on human factors for visualization is **Information Visualization: Perception for Design** (Ware 2004). It is frequently cited and seems to be almost universally admired by Colin Ware's research peers, so it speaks with authority, but it is also very accessible for someone new to the field. It delivers a huge amount of information, nicely packaged in relatively self-contained segments, and always accompanied by excellent illustrations. This means that it can be used as both a read-it-all book or as a reference book.

Ware's book is all about how the eyes and the brain work – how we use symbols, perceive colours, perceive texture, etc. He begins by describing the components of the visual system and the illumination of our environments. This allows him to distinguish, for example, between "pre-attentive" processing and "attentive" processing, and thus discuss shape, continuity, brightness, edges, motion, text, and gestures. All of the details are presented with reference to experiments which explicitly illustrate the points.

This book will not give you ideas for new computer visualizations. There are a few screen grabs at the back of the book, but they are only there to introduce even more human factors principles.

The book ends with an excellent and extensive bibliography which can be used as a route into the literature.

2.3.1.2 Computer Visualization:

The choice of an introductory text for computer visualization is not so clear. The front-runner is "**Information Visualisation: Beyond the Horizon**" (Chen 2004a), which is the second edition of his 1999 textbook. The new edition starts off with some of Chaomei Chen's recent self-referential work mapping the development of the discipline, including fascinating visualizations. But the book is not just a collection of cool pictures – Chen spends Chapters 2 and 3 teaching the craft of how to build these visualizations. For example: how do you project abstract information so that items that are "similar" (whatever that means) are shown close to each other? Subsequent chapters describe other now-standard mapping approaches such as Trees and Maps. The book is largely focused on abstract data spaces, however (Chen's passion is to track citations in the scientific literature) so key algorithms that may be important to MISR, such as fisheye lenses, are not well covered.

Alternatively, or additionally, Natalia and Gennady Andrienko's new book **Exploratory Analysis of Spatial and Temporal Data: A Systematic Approach** (Andrienko et al. 2005) looks promising. The explicit focus on temporal and spatial patterns sets it apart from Chen's book, and the relative newness of the book means that it will be as near to the "cutting edge" as is

possible. One concern is that the book spends a lot of its energy developing data structures, task typologies, etc. which may take it away from descriptions of the visualization problems.

A third approach may be to use **Readings in Information Visualization: Using Vision to Think**, edited by Card, MacKinlay, and Shneiderman (Card et al. 1999). Although this is a compilation, and thus lacks the continuity of a textbook, the authors are excellent and it has been carefully edited to ensure that it covers the field well (it has section on fisheye lenses, for example). Chen refers to this as a "bible of the field." Another concern with this book is that it is seven years old, so a lot has been developed since it was written.

Reading over the past three paragraphs, it seems clear that all three books should be purchased, and the relevant parts of each should be read.

2.3.1.3 Defence Applications

The National Visualization and Analytics Center (NVAC 2006) has assembled an excellent book called **Illuminating the Path: The Research and Development Agenda for Visual Analytics** (Thomas 2005) which can be downloaded for free over the internet. It defines Visual Analytics is the "science of analytical reasoning facilitated by interactive visual interfaces".

2.3.1.4 The Art and the Craft

This section looks at two reference books that offer "wisdom" on visualization and human factors. The first is **Envisioning Information** (Tufte 1990) and was written before the visualization field really got started. Tufte is opinionated, and does not even try to present a complete analysis of the field. Instead he analyses specific cases in great detail, and preaches his own very personal aesthetic.

The second is **Semiology of Graphics** (Bertin 1983) which addresses the underlying patterns in graphical symbology. Key people in the field admire this text greatly, but it is out of print and thus hard to get.

2.3.1.5 Electronic Displays

The best starting place for analysing how display technology affects performance is a recent review paper **Large Display Research Overview** by Czerwinski, Robertson, Meyers, Smith, Robbins, and Tan (Czerwinski et al. 2006).

2.3.1.6 Measures of Effectiveness

One of the pressing concerns in visualization research is the lack of Measures of Effectiveness (MOEs) – articles frequently report quantitative advantages

of their new approaches without any reference to agreed-upon standards or benchmarks. A useful reference on this topic is the special **Empirical Evaluation of Information Visualizations: an Introduction** edition of the International Journal of Human-Computer Interaction, introduced by Chen and Czerwinski (Chen et al. 2000)

2.3.1.7 Inspiration

The final reference book is **How Maps Work: Representation, Visualization and Design** (MacEachren 1995). This book starts with a human factors analysis of how people ingest geographic information (where we attend, what we perceive), builds on that a theory of how maps are understood (knowledge schemata and cognitive representations), and then analyses the use of symbols and icons of maps. Section III specifically looks at maps as Space-Time visualization systems, including an analysis of the use of features such as shape, orientation, colour, and time. Chapter 10 "Should We Believe What We See?" touches on the problem of representing uncertainty.

Unfortunately, the tone of the book is very academic, as illustrated by the following nearly impenetrable example sentence:

> "The link of sign-vehicle to referent through the mediator of an interpretant is given particular emphasis." (pg 244)

2.3.1.8 Journals and Conference Streams

To stay current, it is necessary to read the journals and attend the conferences. These are the major conference streams in Information Visualization:

- IEEE Symposium on Information Visualization (InfoVis) (IEEE Computer Society 1995-2006)
- IEEE International Conference on Information Visualisation (IV) (IEEE Computer Society 1997-2006)
- IEEE Coordinated & Multiple Views in Exploratory Visualization (IEEE Computer Society 2003-2006)
- Conference on Human Factors in Computing Systems (SIG-CHI) (ACM 1981-2006)
- NATO Massive Military Data Fusion and Visualisation (NATO 2002)
- IEEE Visualization Conference (VIS) (IEEE Computer Society 1986-2006)

- Mitre International Conference on Intelligence Analysis (Mitre Corporation 2005)

Two journals of note are:

- IEEE Transactions on Visualization & Computer Graphics (IEEE 1995-2006) (the pre-eminent journal since 1995)
- Information Visualization (MacMillan 2006) (since 2002)

2.3.2 Research Leaders

The following subsections introduce key leaders in the research community, some of whom work at centers of excellence such as the following:

- Westgrid (Westgrid 2006)
- Electronic Visualization Lab (Electronic Visualization Laboratory 2006)
- Graphics and Visualization Center (Graphics and Visualization Center 2006)
- Pacific Northwest National Laboratory (Pacific Northwest National Laboratory 2006)

2.3.2.1 Colin Ware

Colin Ware (Ware 2006) is Director of the Data Visualization Research Lab which is part of the Center for Coastal and Ocean Mapping at the University of New Hampshire (UNH 2006). Ware specializes in advanced data visualization and he has a special interest in applications of visualization to Ocean Mapping. He combines interests in both basic and applied research and he has advanced degrees in both computer science (MMath, Waterloo) and in the psychology of perception (PhD, Toronto). Many of these relate to the use of color, texture, motion and 3D displays in information visualization. His approach is always to combine theory with practice and his publications range from rigorously scientific contributions to the Journal of Physiology and Vision Research to applications oriented articles in ACM Transactions on Graphics and IEEE Transactions on Systems, Man and Cybernetics.

Publications by Ware include: (Arsenault et al. 2006; Bartram et al. 2002; Irani et al. 2003; Laramee et al. 2001; Salerno et al. 2004; Ware 2003; Ware 2004; Ware 2006; Ware et al. 1999)

2.3.2.2 Natalia Andrienko and Gennady Andrienko

Dr. Natalia Andrienko and Dr. Gennady Andrienko (Andrienko et al. 2006) are managers of the SPADE team on research and technology at the Fraunhofer Institute. They received their Master degrees in Computer Science from Kiev State University in 1985 and 1986, and a Ph.D. equivalent in Computer Science from Moscow State University in 1992 and 1993, respectively. They worked on knowledge-based systems at the Mathematics Institute of Moldavian Academy of Sciences (Kishinev, Moldova), then at the Institute on Mathematical Problems of Biology of Russian Academy of Science (Pushchino Research Center, Russia). Since 1997 Drs. Andrienko have had research positions at the Fraunhofer Institute. They are active members of several commissions of the International Cartographic Association (Commission on Visualization and Virtual Reality, Commission on Maps and the Internet, and Commission on Theoretical Cartography). Their research interests and experiences are interactive computer graphics, automated knowledge-based cartographic visualisation, information visualisation, spatial data mining, and visual geo-data exploration.

Publications by the Andrienkos include: (Andrienko et al. 2003; Andrienko et al. 2006; Andrienko et al. 2005)

2.3.2.3 Chaomei Chen

Chaomei Chen (Chen 2006) is an Associate Professor in the College of Information Science and Technology at Drexel University, Philadelphia, USA. He is the author of **Mapping Scientific Frontiers: The Quest for Knowledge Visualization**, **Information Visualization: Beyond the Horizon**, and **Visualizing the Semantic Web**. He has invented ways to map out and visualize the development of academic disciplines, such as String Theory, using online citation indexes.

Publications by Chen include: (Chen 2000; Chen 2003; Chen 2004a; Chen 2004b; Chen 2005; Chen 2006; Chen et al. 2000; Chen et al. 2001; Geroimenko et al. 2004; Geroimenko et al. 2005)

2.3.2.4 Jock Mackinlay

Jock Mackinlay (Mackinlay 2006) is a leader in information visualization, particularly for abstract data spaces, and works out of Xerox PARC. He collaborated with the User Interface Research Group to develop many novel applications of computer graphics for information access, coining the term "Information Visualization". He co-invented a number of visualizing techniques, including Cone Trees and Perspective Walls. His current research is exploiting advances in flat panel displays and graphics cards that enable personal computers with 6-8 monitors and may also eliminate seams.

Publications by Mackinlay include: (MacKinlay 1986; Mackinlay et al. 1991)

2.3.2.5 Alan MacEachren

MacEachren (MacEachren 2006) has a background in cartography and environmental cognition and has worked for years in geographic representation and geovisualization. He is specifically interested in human mental representation of space and space-time, integration of geographic visualization with other knowledge construction methods, GeoVirtual environments, and geocollaboration. He wrote the seminal text **How Maps Work: Representation, Visualization and Design** as mentioned above.

Publications by MacEachren include: (Howard et al. 1996; MacEachren 2006; MacEachren 1995; MacEachren et al. 2004; MacEachren et al. 2001; Thomson et al. 2005)

2.3.2.6 Ben Shneiderman

Ben Shneiderman (Shneiderman 2006) is a Professor in the Department of Computer Science, University of Maryland, College Park. He is Founding Director (1983-2000) of the Human-Computer Interaction Laboratory, and Member of the Institute for Advanced Computer Studies and the Institute for Systems Research at UMCP. Dr. Shneiderman is the author of Software Psychology: Human Factors in Computer and Information Systems (1980). In 1999 he co-authored **Readings in Information Visualization: Using Vision to Think** with Stu Card and Jock Mackinlay, then in 2003 continued in this direction by co-authoring **The Craft of Information Visualization: Readings and Reflections** with Ben Bederson. He is an advisor for treemap supplier HiveGroup and for ClockWise3D, as well as a member of the Technical Advisory Board for ILOG.

Publications by Shneiderman include: (Card et al. 1999; Johnson et al. 1991; Plaisant et al. 1995; Shneiderman 1996; Shneiderman 2006; vanDam et al. 1999)

2.3.2.7 Jim Thomas

Jim Thomas (Thomas 2006) is director of the Department of Homeland Security's National Visualization and Analytics Center and a Laboratory Fellow at Pacific Northwest National Laboratory. Thomas sits on several national and international science and technology boards for universities, states and industry. He co-wrote **Illuminating the Path: The Research and Development Agenda for Visual Analytics** (Thomas 2005).

Publications by Thomas include: (Thomas 2005; Thomas et al. 1999; Thomas 2006; Thomas et al. 2005; Wise et al. 1995)

2.3.2.8 Michelle Zhou

Michelle Zhou (Zhou 2006) is a research manager at IBM T. J. Watson Research Center, where she manages the department of intelligent multimedia interaction. She received a Ph.D. in Computer Science from Columbia University. Her research interests include intelligent user interfaces for information search and analysis, context-sensitive multimedia presentation authoring, and dynamic and context-driven information visualization. Dr. Zhou has authored and coauthored a number of papers in automated generation/authoring of animated 3D information visualization and multimedia presentations, including topics on data characterization, visual task characterization, planning-based and machine-learning approaches to dynamic and adaptive visual illustration generation.

Publications by Zhou include: (Zhou 1999; Zhou 2006; Zhou et al. 1996)

2.3.2.9 Carl Gutwin

Carl Gutwin (Gutwin 2006)is associate professor in the Department of Computer Science and the director of the HCI lab at the University of Saskatchewan. His main research areas are Computer-Supported Cooperative Work, Information Visualization, and Information Retrieval. Gutwin is a specialist in Fisheye Lenses, and has published on many other visualization topics.

Publications by Gutwin include: (Cockburn et al. 2006; Gutwin 2006; Gutwin et al. 2004; Irani et al. 2006; Mould et al. 2004; Nacenta et al. 2006)

2.3.2.10 Mary Czerwinski

Mary Czerwinski (Czerwinski 2006) is Microsoft's leading specialist in the human factors of electronic displays, including novel information visualization and interaction techniques across a wide variety of display sizes. Her background is in visual attention and user interface design and she holds a Ph.D. in Cognitive Psychology from Indiana University in Bloomington.

Publications by Czerwinski include: (Bederson et al. 2004; Czerwinski et al. 2003; Czerwinski 2006; Czerwinski et al. 2006; Robertson et al. 2002a; Robertson et al. 2002b; Robertson et al. 2005)

2.3.2.11 William Wright

Bill Wright and colleagues formed Oculus in 2002 to apply information visualization solutions to commercially-viable applications. His work on DARPA's Command Post of the Future earned him a DARPA-Tech "Bridging the Gap" award (DARPA 2004). He was also instrumental in developing the GeoTime information visualization system for military

applications (Kapler et al. 2004a). Wright and his company Oculus are based in Toronto.

Publications by Wright include: (Jonker et al. 2005; Kapler et al. 2004a; Kapler et al. 2004b; Shuping et al. 2004; Wright et al. 2002a; Wright et al. 2002b; Wright et al. 2005)

2.3.3 Pressing Questions and Work Currently Underway

There are many different analyses of what the pressing questions are, as discussed in the following paragraphs.

2.3.3.1 Foley's List

Foley, six years ago, offered the following list (Foley 2000) of the top ten problems in graphics:

1. Fill the gap between image-based and geometric modeling techniques.
2. Fill the gap between motion-capture animation and simulation/procedural animation.
3. Creative information visualization.
4. Automated creation of information and scientific visualizations.
5. Abstracting away from reality.
6. Display more pixels.
7. Display fewer pixels.
8. Unified graphics architectures.
9. User interfaces for 3D creativity.
10. Truly immersive virtual reality.

2.3.3.2 Chen's List

Chen responded in 2005 by blowing open Foley's Problem 3 into the "Top 10 Unsolved Information Visualization Problems" (Chen 2005). Chen's list is:

1. Usability
2. Understanding elementary perceptual–cognitive tasks

3. Prior Knowledge
4. Education and Training
5. Intrinsic Quality Measures
6. Scalability
7. Aesthetics
8. Paradigm shift from structures to dynamics
9. Causality, visual inference, and predictions
10. Knowledge domain visualization

2.3.3.3 NVAC's List

The National Visualization and Analytics Center (Thomas 2005), in a series of sections called "Technology Needs," has identified deficiencies and requirements such as the following:

- visualizations for spatial and temporal data (pp 8, 86)
- visualizing uncertain, incomplete, and misleading data (pp 8, 87, 132)
- ways to evolve data quality and reliability metadata in parallel to data processing stages (pg 11)
- visualizations suitable for communicating to public (pp 13, 143)
- solutions to privacy concerns (pp 13, 14)
- visualizations for visual analytic work flows (pg 42)
- collaborative visual analytics in high-stress situations (pp 62, 142)
- more automated data pre-processing
- visualizing small changes in large datasets (pg 132)

We draw attention in particular to the third-last bullet, which crops up in many current publications as the following more general topic of interest:

- remote collaborative visualization

2.4 Status of MISR Topics of Interest

The following subsections and paragraphs review articles that were found in the literature search that address the MISR topics of interest listed in Section 2.1.2.

2.4.1 Space-Time Visualization

In general, a small fraction of the Visualization research addresses issues of space and time mapping, and particularly few address the difficult problem of co-visualizing time with spatial information. The most successful, and the most relevant to MISR, are:

- GeoTime developments by Oculus (Kapler et al. 2004a; Kapler et al. 2004b; Wright et al. 2002a) (Oculus 2006).
- Wright's work with blobology (Wright et al. 2002b) and
- the Starlight research (Risch 2006)

The following sections refer to bibliography entries that address this further:

2.4.1.1 Books

(Andrienko et al. 2005; MacEachren 1995; Peuquet 2002)

(Tufte 1997a)

2.4.1.2 Conference and Journal Papers

(Shuping et al. 2004) (Andrienko et al. 2003) (Livnat et al. 2005b)

(Palanque 1995) (Livnat et al. 2005a) (Hao et al. 2005)

(Shanbhag et al. 2005) (Saraiya et al. 2005) (Kapler et al. 2004a)

(Wright et al. 2002b) (Kapler et al. 2004b) (Gouin et al. 2002)

(Taylor 2002) (Llinas et al. 2002) (Bobrow et al. 2005)

(Hara et al. 1995; Hengst et al. 2004; Moere 2004)

2.4.1.3 Corporate Brochures

(Oculus 2006)

2.4.2 Visualizing Attribute Information

The visualization literature is rich in ideas and applications for visualizing attribute information in many different ways in order to reveal the relationships between objects and classes of object. This typically takes the form of TreeMaps, Hierarchical Maps, and cluster maps projected onto real and virtual spaces. We selected the following as being representative.

(Robertson et al. 2002b) (Fekete et al. 2002) (Johnson et al. 1991)

(Robertson et al. 2002a) (Robertson 1998) (Stolte et al. 2002)

(Robertson et al. 2005) (Wise et al. 1995) (Robertson et al. 1991)

(Balzer et al. 2005) (Zhao et al. 2005) (Börner 2005)

(Gouin et al. 2002) (Llinas et al. 2002) (Munzner et al. 2003)

2.4.3 Visualizing What is Unknown

We found only two papers that addressed the problem of representing and visualizing what is not known, and both were by the same author:

(Hew 2003b) (Hew 2003a)

There were also some articles that dealt with visualizing coverage maps, which by implication also visualize non-covered areas:

(Wright et al. 2002b)

2.4.4 Defence Applications

The following papers specifically looked at defence requirements, developed defence visualization solutions, or used a defence application as an example:

(Alberts et al. 2002) (Hennessy et al. 2003) (CIA 1995)

(Hall 1999) (Heuer 1999) (Alward 2002)

(Grinstein et al. 2003) (Clark et al. 2004) (Risch 2006)

(Wright et al. 2002b)

The following papers specifically apply to Meteorology and Oceanography (METOC) applications:

(Basu et al. 2002) (Kitsiou et al. 2001) (Jimenez et al. 2003)

2.4.5 Visualizing Uncertainty

These are the few papers that we found on visualizing uncertainty:

(Basu et al. 2002) (Hosbond et al. 2003) (van Dorp et al. 2002)

(MacEachren 1995) (Finger et al. 2002) (Wittenbrink et al. 1996)

(Thomson et al. 2005) (Ehlschlaeger et al. 1997) (Merrick et al. 2003)

(Wickens 2005) (Clausner et al. 2005) (Horn 2005)

(Amar et al. 2005; Hara et al. 1995)

2.4.6 Domain Awareness

We found no papers that explicitly addressed the problem of achieving a holistic view over a wide spatial area and over an extended period of time.

2.4.7 Information Overload

Information overload is obviously recognized as a problem associated with scaling-up visualization systems. We found very few papers that address the problem, however, and none that are specifically for a MISR application. These are the ones we found:

(Krüger 1998) (Eick et al. 2000) (Woods et al. 2002)

(Aasgaard 2002) (Ericson et al. 2005) (Mould et al. 2004)

(Jonker et al. 2005)

2.4.8 Human Factors in General

There are, of course, many papers that use Human Factors techniques to measure and evaluate Visualization strategies. These are the ones that we found:

2.4.8.1 Books

(Gibson 1987) (Ware 2004) (Stone et al. 2005)

2.4.8.2 Conference and Journal Papers

(Nowell et al. 2002) (Kim 2004) (Smallman et al. 2001)

(Tversky et al. 2002) (Robertson et al. 2005) (Healey et al. 1993)

(Ware 2003) (Kirschenbaum et al. 1995) (Johnson 1995a)

(Johnson 1995b) (O'Donnell 1995) (Hornbæk et al. 2002)

(Laramee 2002) (Laramee et al. 2001) (Saraiya et al. 2005)

(Bergman et al. 1995) (Ware et al. 1999) (Baudisch 2006)

(Fisher et al. 2006) (Mould et al. 2004) (Dennis et al. 1998)

(McGuffin et al. 2005) (Mezzanotte 1995) (Pirolli et al. 2005)

2.4.8.3 On-Line Articles

(Taylor 2006) (May et al. 2006) (Wickens 2005)

(PARC 2006)

2.4.8.4 Thesis

(Nowell 1997)

2.4.9 Measures of Effectiveness

In response to item (5) from Chen's list in 2.3.3.2, we also searched for papers about Measures of Effectiveness for visualization research. The primary source is the special issue of the International Journal of Human-Computer Studies, as already mentioned:

(Chen et al. 2000)

as well as the following:

(Taylor 2006) (Salerno et al. 2004) (Endsley et al. 2000)

(Hengst et al. 2004)

2.4.10 Display Technologies

We found the following papers on display technologies, and on the problems associated with making algorithms work in various display environments.

2.4.10.1 Conference and Journal Papers

(Raskar 2004) (Eick et al. 2000) (Czerwinski et al. 2006)

(Czerwinski et al. 2003) (Laramee 2002) (Laramee et al. 2001)

(Tory et al. 2006) (Terrenghi et al. 2006) (Majumder et al. 2005)

(Chinnock 2005) (Baudisch 2006) (Dempski et al. 2006)

(Swindells et al. 2004) (Seetzen et al. 2004) (Horn 2005)

(Yamamoto et al. 2006) (vanDam et al. 1999)

2.4.10.2 Corporate Brochures and Web Pages

(Qinetiq 2004) (May et al. 2006)

2.5 Other Topics of Interest

Many of the articles that we found, though not explicitly addressing the questions raised in the project, may be of value to the ARMADA project. The following subsections provide links to those.

2.5.1 Review Articles and textbooks

The following articles address more than one topic. Some were written as introductions to, or summaries of, the visualization field and some are addressing topics that span the various disciplines:

(Chen 2000) (Dodge 2004) (National Science Foundation 2006)

(Tory et al. 2004a) (Clark et al. 2004) (McCormick et al. 1987)

(Wikipedia 2006) (Rushmeier et al. 1997) (Mitre Corporation 2005)

(Gelernter 2004) (Lima 2006) (SLIS 2006)

The following on-line articles set out to be master lists of visualization research, but not all live up to their ambitions:

(Acevedo 2006a) (Acevedo 2006b) (Info Vis Wiki 2006)

(Cribbin 2004) (Reed et al. 1997) (Nooface 2006)

(Graham 2006) (SLIS 2006)

The bibliography lists the following visualization textbooks:

(Bederson et al. 2003) (Card et al. 1999) (Chen 2003)

(MacEachren 1995) (Ware 2004) (Spence 2000)

(Andrienko et al. 2005) (Keller et al. 2005) (Chen 2004a)

2.5.2 Philosophical Articles

The following articles discuss general principles and visions for visualization applications:

(Gaither et al. 2004) (Hutchins 1996) (MacEachren 1995)

(Pylyshyn 2003) (Pfitzner et al. 2001) (vanDam 2001)

(Tory et al. 2004b) (Chen 2005) (Johnson et al. 2004)

(Tufte 1997b) (Tufte 1997a) (Tufte 2003)

(Tufte 2006)

2.5.3 Visualization Architectures

The following papers express opinions about what "architectures" (in the informal sense of "high-level organization strategies") should be used:

(Kohlhammer et al. 2004) (Rogowitz et al. 1993) (Kirschenbaum et al. 1995)

(Chi 2000)

2.5.4 Collaboration

The following papers describe experiments and experience with collaborative visualization systems:

(Bauer et al. 1999) (Olson et al. 2001) (Convertino et al. 2005)

(Electronic Visualization Laboratory 2006) (Börner 2005)

(Hall 1999)

2.5.5 Requirements

The following articles and books discuss where the visualization deficiencies are, and thus what requirements are outstanding:

(Alberts et al. 2002) (Hennessy et al. 2003) (Lymon et al. 2003)

(CIA 1995) (Hall 1999) (Heuer 1999)

(Pirolli et al. 2005) (Espinosa et al. 1999) (Foley 2000)

(Burrough et al. 1995) (vanDam et al. 1999) (Johnson et al. 2006)

(Jonker et al. 2005) (Alward 2002) (Taylor 2002)

(Grinstein et al. 2003) (Amar et al. 2005) (Chen 2005)

2.5.6 Demonstrated Ideas

A number of papers simply report on a visualization idea that was implemented, or a problem that was solved using visualization techniques:

(Gansner et al. 2005) (Goodall et al. 2005) (W.R. Systems 2006)

(Buja et al. 1991) (Ankerst et al. 1998) (MacEachren et al. 2004)

(Barlow et al. 2001) (Beermann et al. 2005) (Eick 2000)

(Fekete 2005) (Fekete 2004) (Fekete et al. 2002)

(Furnas 1986) (Smallman et al. 2001) (Ward 1994)

(Zhou et al. 1996) (Andrienko et al. 2003) (Wright et al. 2005)

(Healey et al. 1993) (Fua et al. 1999) (Livnat et al. 2005b)

(Palanque 1995) (Card et al. 1991) (Balzer et al. 2005)

(Zhao et al. 2005) (Brandes et al. 2005) (Wilkinson et al. 2005)

(Hao et al. 2005) (Moere 2004) (Bergman et al. 1995)

(Börner 2005) (Porathe 2002) (Arsenault et al. 2006)

(Data Visualization Research Lab 2006) (US Army 2006)

(Gutwin et al. 2004) (Irani et al. 2006) (Cockburn et al. 2006)

(Wong et al. 2003) (Chen 2004b) (Risch 2006)

2.5.7 Books About Graphic Design Principles

The database lists books such as Tuft's *The Visual Display of Quantitative Information*, which can best be described as "about graphics". These are:

(Bertin 1981) (Bertin 1983) (Brown et al. 1995)

(Tufte 1983) (Tufte 1990) (Tufte 1997a)

(Wilkinson 1999) (Harris 1999)

2.5.8 Visual Analytics

The following references address topics of particular concern for visual analytics:

(Yu et al. 2004) (Card et al. 1999) (Thomas et al. 1999)

(Wright et al. 2005) (Wilkinson et al. 2005) (Thomas et al. 2005)

(Andrienko et al. 2005) (Risch 2006)

2.5.9 Quirky Articles

Finally, we list a series of articles that don't fit into any reasonable classification. First, two very different sources on the topic of visualizing abstract data as an "information landscape":

(Dodge 2004) (Gibson 1984)

We have included two books by Geroimenko on visualizing the Semantic Web:

(Geroimenko et al. 2004; Geroimenko et al. 2005)

3 Product Review

3.1 Introduction

3.1.1 Approach

Our general approach to the product review approach was to allow the literature survey to get an early start to identify some of the state of the art research, product evaluations and the key areas of information visualization. The next task was to start canvassing a variety of information sources to come up with a comprehensive list of information visualization products that are currently or soon to be available. That initial survey was very broad and did not attempt to aggressively filter out any related hardware or software solutions.

After some internal review and iterations, a lengthy list of products was identified. We then chose a subset of the products that met the following criteria:

- the developers provided sufficient information that we could talk about the product
- the product was relevant to the goals of this contract
- the product appeared to be immediately or imminently available
- the technology had some applicability to MISR

We started with over a hundred products, but then chose a subset of approximately twenty products that we reviewed in more detail. These twenty products were investigated using available literature, demonstrations, reviews, in-house experience or any other resources that could support our assessment.

3.1.2 Priorities

Ultimately, our intent was to deliver product reviews that satisfy the goals of the contract as summarized in Section 1. That is:

- to establish the state-of-the-art for the field of Information Visualization
- show preference towards information visualization products that in some way complement and/or serve the needs of MISR and ISR
- provide some insight into technologies that aid in the visualization of uncertainty and representation of the unknown. We found that products tend not to focus on this specific goal, so much as enable it through features available in the project.
- pay specific attention to technologies that help reduce the challenges of information overload. More emphasis exists in the literature review section, but there are some technologies that simplify/condense information into a usable format that is more readily exploited by operators.

Some trends clearly emerge when looking at the types of products that are available. Information visualization appears to be driven by four markets:

- Defence
- The financial community
- Internet, and in particular, the web
- Enterprise knowledge management catering to corporations

These four areas clearly need advanced information visualization tools – they are all driven by the need to make sense of, and see patterns in, large amounts of information, sift through a potentially high signal-to-noise ratio, and support the end user in identifying knowledge that supports their decision-making process. The Internet is a unique market in that it is nebulous and represents a spectrum of users and requirements, but end user requirements are still similar to those in the defence, financial and corporate markets.

3.1.3 Review Criteria

Typically, Off-The-Shelf surveys start with a detailed assessment of requirements and trade-off criteria. To do this, one must start with a set of requirements that are often system- or project-specific. In the case of this survey, the requirements are very broad so the review criteria were equally broad. We thus reviewed products against the following criteria;

- Product Type (open source, academic, commercial)
- MISR Relevance (direct, indirect, n/a)
- ISR Relevance (direct, indirect, n/a)
- Product category (spatial, search, management, overload management, uncertainty visualization, trend analysis)

We also provided a reference to the product, and, where applicable, added our own comments and observations on the product.

3.1.4 Scope

As with the literature review survey, we have identified scope that we will and won't be reviewing. We intend to research the following areas:

- Spatial visualization:
- Knowledge visualization:
- Context and depth navigation
- Linkage and large data set management
- On-Line Analytical Processing (OLAP) and data mining technologies

3.2 Hardware Products

Hardware technologies facilitate visualization by providing features that improve the operator's experience. As information gets more complex, it typically places more demands on the operator to digest and navigate the information. Hardware can provide improvements that allow the operator to see information more clearly, more effectively and/or more comprehensively.

3.2.1 2-D Displays

Two dimensional display technology remains a staple of visualization. Although the scientific and commercial communities continue to look for alternatives, human visualization relies heavily on two-dimensional representations. This can probably be traced back to physiological traits as well as learned behaviours that start at a very early age.

Two dimensional hardware technology typically focuses on delivering more information to users more quickly and in a more cost effective manner. As a result, the advances are typically not paradigm shifts, but rather refinements and incremental enhancements to existing capabilities.

Another area of interest, but beyond the scope of this report is the ability to interact with, and manipulate information presented on two dimensional screens. Input devices and spatial manipulation devices support, however, are not true visualization tools so we have not included them. They are a capability that is worth being aware of when considering potential 2-dimensional technology advances.

3.2.1.1 Mitsubishi MegaWall

Knowledge walls provide technology that gives users integrated display of two dimensional information. Knowledge walls can be interactive, or can be display-only devices. They are unique in that they deal with a huge number of pixels, typically cover several square feet (or more), and are a vital situational awareness tool in command and control environments. The technology of knowledge walls is split between the presentation (the monitors/screens themselves) and the driver hardware and technology that interfaces decision support software and systems to these monitors. When dealing with so many pixels, pushing information to the screens with adequate refresh rate and low latency is not trivial.

The Mitisubishi MegaWall (http://www.mitsubishi-megaview.com/) displays are large (50" to 67") stackable rear projection displays that offer a variety of resolutions (XGA to SXGA+). Combined with their optional input board, a single image or video can be scaled to be displayed on a 5 x 5 display array. These displays can be used for large shared overview and current situation displays in large operation centers, such as the one in Figure 5).

This technology is relevant to Surveillance Operations Centers (SOCs) as it provides an incremental and scalable solution for increasing display surface over time as required. Screen real estate can be re-assigned according to operational needs.

Figure 5. *City of Austin Megawall*
The Mitsubishi MegaWall display in Austin Texas combines information for Transportation, Emergency and Communication. (source http://www.mitsubishi-megaview.com/docs/applications/).

3.2.1.2 ZenView Command Centre

The ZenView system is another type of "knowledge wall", albeit tailored for more compact installations and a small number of users. Rather than focus on providing a stateboard for a command center, the ZenView system is essentially a very large, multi-paned monitor solution for operators.

ZenView Command Centre (http://www.digitaltigers.com/displays-commandcenter.shtml) products combine six LCD displays of various sizes (17" to 24" wide-screen) to form one large display (see Figure 6). Depending on the monitor configuration resolutions from 3840 by 2048 combined resolution with a 600:1 contrast ratio and a 300 cd/m² brightness to 5760 by 2400 with a 1000:1 contrast ratio and a 500 cd/m² brightness are achieved.

The product includes the Zenview Manager which is an enhanced multi-display manager. It allows for the typical windows dual-monitor display functionality as well as the ability to add an independent taskbar to the bottom of each display. The borders between the monitors disrupt the flow of images that span multiple monitors.

Figure 6. *Zenview Command Center 21S*
ZenView is a knowledge wall for more compact installations and a small number of users. (source http://www.digitaltigers.com/displays-commandcenter.shtml).

3.2.2 3-D Displays

The use of 3D displays in MISR is questionable as most of the data is either well suited to being viewed as complementary data to a 2D GIS display, or the data consists of many more dimensions. Users tend to be sufficiently happy with simulated three dimensional displays where software technology provides users with a perceived three dimensional representation, while using standard, affordable two dimensional technologies.

Three-dimensional applications still have a role, but there are some challenges with true information visualization (other than typical terrain or three-dimensional model visualization). When looking at hierarchical or otherwise structured data sets, three dimensional representations require that some information be obscured by not being at the highest level of the viewing field.

Three dimensional projects are able to provide a simulated “floating display” that does not really convey three dimensional structure, but does project what appears to be a spatially-locked, image. This technology can be of interest for providing ad hoc presentations to a group of individuals.

Many software applications use shading, lighting, scale, etc to provide perceived depth. Being able to use a proper third dimension to convey information would allow one more variable to be presented to the user in addition to shading, lighting, scale, although it is questionable whether depth would work in conjunction with all of the other aspects of display (namely shading, lighting and perspective), or simply do a better job of presenting them to the user.

3.2.2.1 Kodak 3D Stereo Display

The Kodak 3D Stereo Display (http://www.physorg.com/news763.html) provides a resolution of 1280 x 1024 pixels, a field of view that gives the viewer the feeling of floating in a movie theatre about 1.5 screen heights away from the screen. It is compatible with any industry-standard video or still image source, and operates with PC, Mac, or SGI platforms using any off-the-shelf video card, such as NVIDIA or any Microsoft DirectX-, Direct 3D or Open GL-compatible cards.

The user sits in front of a system (see Figure 7) that creates a virtual image of two high-resolution LCD displays, one for each eye. The user looks into two "floating balls of light" that provide each eye a view of a magnified image of one of the two displays. The combination of the wide field of view, the virtual image, and the absence of imaging artefacts eliminates many of the sources of eyestrain that are present in other stereoscopic systems. It claims to have an easier method for visually locking in on a "sweet spot" so that viewers can spend more time viewing critical data without suffering eyestrain or loss of image resolution.

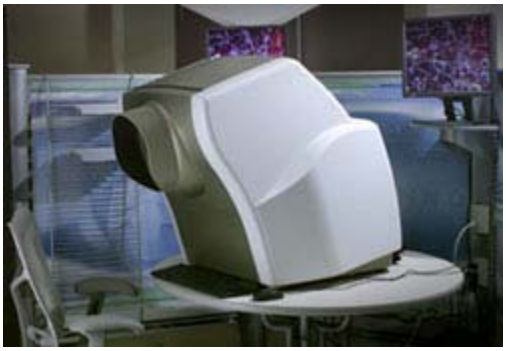


Figure 7. *Kodak 3D Stereo Display*
The Kodak 3D Stereo Display does not require a dim lighting environment, and can be used with normal office lighting. (source http://www.physorg.com/news763.html).

3.2.2.2 Polaris Sensor Technologies

Polaris Sensor Technologies LCD3D (http://polarissensor.com/3DDisplay.htm) provides a 3D display similar in form to a conventional screen, as shown in Figure 8. Using dual stacked liquid crystal display, the system simultaneously displays two incoming video streams as a right-eye and left-eye view which are then viewed using low-cost 3D glasses. A 10.4" product is available now, with a larger 17" prototype expected to be completed in mid-2006.

Figure 8. *The Polaris 10.4" LCD 3D*
Polaris Sensor Technologies LCD3D display uses dual stacked liquid crystal displays to simultaneously display separate video streams for the right-eye and left-eye. (source http://polarissensor.com/3DDisplay.htm).

3.2.3 Interactive Displays

Interactive displays allow the user to manipulate a dataset, and turn the presentation layer into an input device. This technology has been available for many years in cell phones, portable devices, laptops, appliances, etc. The advances have typically been in increased ruggedness, lower cost, improved precision, and software advances that better exploit the input capabilities.

These tools are valued for mission planning, interdiction planning and highlighting tracks for operators to focus on. They can also be helpful to support operators in their day to day activities. They can be useful as an interactive track management tool, allowing operators to select and manipulate tracks. The operator could call up intelligence documents instantly from tracks and view the information in a single, interactive environment.

3.2.3.1 *Interactive DataWall*

Knowledge walls have been developed that include touch-sensitivity to effectively integrate mouse/gesture capability within the display. This is an excellent advance for command and control, or really any business/domain intelligence applications where the user wishes to interact with the display. Applications can include interactive and enhanced white-boarding, data navigation and display, collaborative manipulation of objects, etc.

Air Force Research Laboratory Information Directorate's (AFRL/IF) Interactive DataWall (http://www.rl.af.mil/programs/ADII/adii_dw.html) consists of three horizontally tiled LCD projectors (see Figure 9) each displaying 1280 x 1024 pixels for a combined resolution of 3840 x 1024 pixels across a 12' x 3' screen area. Combined with a custom speaker-independent voice activation and a wireless pointing device using camera tracked laser pointers users can interact with the applications as if they were using a wireless mouse.

Figure 9. *The Interactive DataWall*
AFRL's Interactive DataWall consists of three horizontally tiled LCD projectors combined with camera-tracked laser pointers. (source http://www.rl.af.mil/programs/ADII/adii_dw.html).

3.2.3.2 Northrop Grunman TouchTable

Northrop Grumman offers a product that uses similar technology to AFRL's, but with a touch table rather than wall. This opens up different types of applications, and has led to interesting advances in the software features integrated into the system for interacting with the data. Simple gestures support zoom in/out, selection and movement of data within the display.

The Northrop Grumman TouchTable (http://www.touchtable.com/) provides an 84 inch surface capable of displaying a 1600x1200 pixel image projected onto the surface, as shown in Figure 10. The TouchShare software framework provided with it enables developers to utilize the touch sensitive functions of the table to allow users to interact with the display.

Figure 10. *The Northrop Grunman TouchTable*
Users can draw, measure and interact with objects displayed on the touchtable. (source http://www.touchtable.com/).

3.2.3.3 Zebra Holo-touch Workstation

Some interactive displays combine interaction with three dimensional display capabilities. One such example (see Figure 11) is the Zebra Imaging holographic imager and holo-touch workstation (http://www.zebraimaging.com/html/imager_workstation.html). These two components work together to provide a semi-interactive hologram. The Zebra Imaging imager is required to produce a hologram that is then displayed using the holo-touch workstation. The holo-touch workstation has an integrated 3D stylus that allows the viewer to "touch" the holographic images and perform functions such as measuring virtual objects within the holographic image, and interacting with the computer data. The stylus also provides force feedback to give the illusion of touching objects and surfaces.

This capability could be of interest in operations where Air, Sea or Land forces are working together simultaneously requiring a means of visualization assets in an area with some appreciation of depth, visual cues for estimated times of arrival, etc.

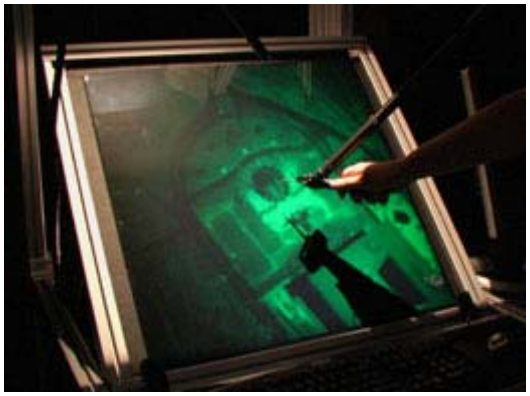


Figure 11. *The Holo-touch Workstation*
The holo-touch workstation has an integrated 3D stylus that allows the viewer to "touch" the holographic images and perform functions such as measuring virtual objects within the holographic image, and interacting with the computer data. (source http://www.zebraimaging.com/html/imager_workstation.html).

3.2.3.4 Smart Boards

SMART Board interactive whiteboards (http://www2.smarttech.com/st/en-US/Products/SMART%2BBoards/Front%2BProjection/Default.htm) display a computer image and are touch-sensitive. Users can thus use the whiteboard as the input device to a computer, as shown in Figure 12, or share whiteboard content across a network. In many respects they are thus like the TouchTable in Section 3.2.3.2, except that it is intended to be mounted vertically. Some versions of SmartBoard use an LCD display, while others use a projector.

Figure 12. *SmartBoard Interactive Whiteboard*
SmartBoards display computer data on a large white board (64" or 77" diagonal) and digitize material that is written on the board.

3.3 Software Products

Software products enable visualization either by providing turnkey solutions and applications, or by providing functionality that enables customers to develop unique visualization products. Software advances are being led both on the military and on the corporate front. Commercial organizations also have urgent information visualization requirements that support their business intelligence, stateboard and situational awareness capability, data mining and reporting requirements. As such, many of the software innovations are being targeted at financial and corporate requirements, yet still have applicability in the Maritime ISR domain due to common data mining and information visualization challenges.

Software solutions should continue to strive towards open standards and architectures, such that visualization tools and supporting frameworks can evolve rather than require substantial re-structuring or re-building of knowledge management systems.

3.3.1 General Purpose Toolkits

General purpose toolkits are libraries that allow users to develop their own unique information visualization applications. These toolkits typically do not deliver turnkey results or user applications, but enable engineers and developers with the ability to develop advanced information visualization applications. Low-level APIs and Software Development Kits (SDKs) such as OpenGL, DirectX, QT and other drawing libraries are not covered since they are considered too low-level to be information visualization toolkits.

3.3.1.1 ILOG Discovery

ILOG merits mention given their significant focus on discovery and presentation of information. They have a number of products that deal with the manipulation of data, business rules and the presentation layer.

One of their tools, ILOG Discovery (http://www2.ilog.com/preview/Discovery/), is a proof of concept data analysis and data exploration tool. It provides the ability to access data from a variety of sources such as databases and flat files (up to a million records) and display the data in various views and interactively browse and edit the data.

ILOG Discovery provides various visualizations of the data such as histograms, distributions, graphs, data maps, and hierarchies. It allows multiple data sets to be loaded and displayed at the same time with the multiple views being visible at the same time. Users can zoom and pan each display and are provided with an overview and details view using ILOG Discovery's object inspector, table viewer and tooltips functionality.

ILOG Discovery provides a library and a documented API which allows its features such as views, commands, predefined dialog boxes, and various interactive tools to be included into Java programs.

ILOG Discovery is not available for purchase, but it can be used for free by academics and selected commercial organizations.

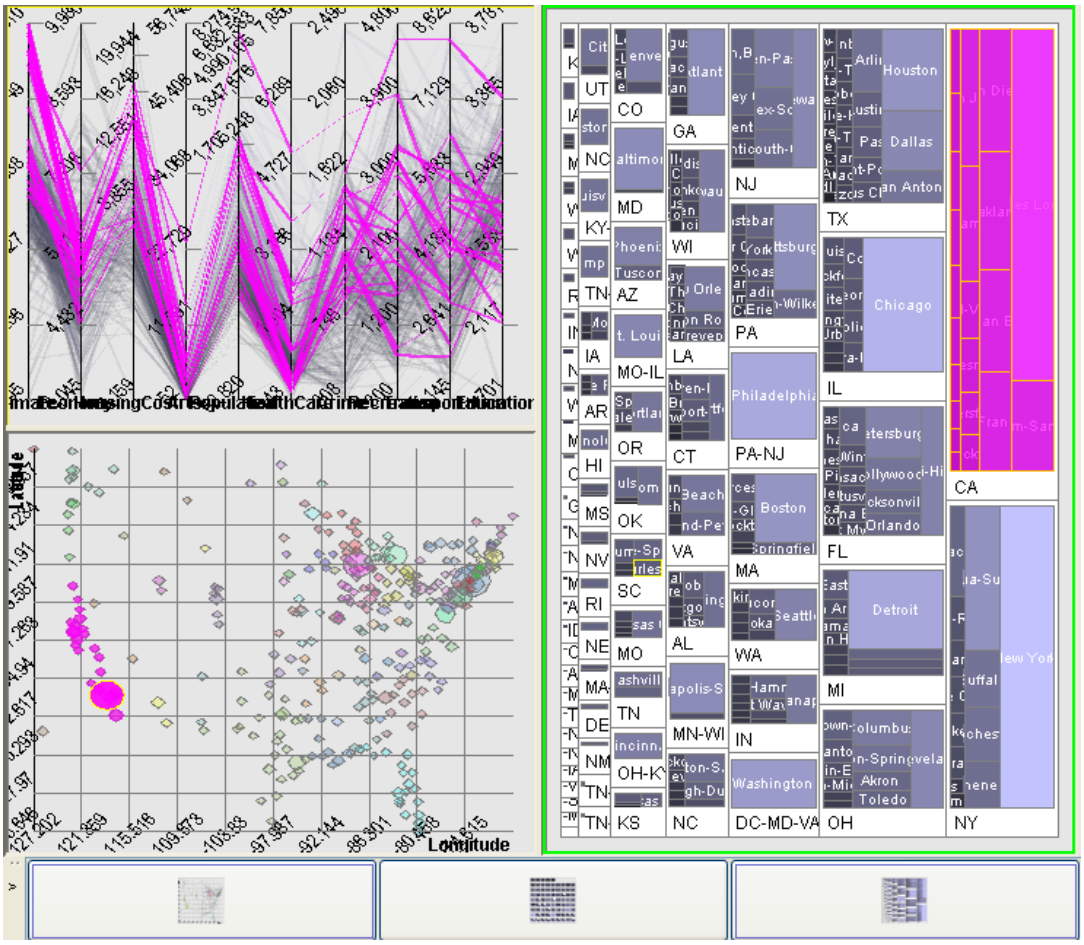


Figure 13. *ILOG Discovery*

ILOG has developed an experimental visualization tool for analyzing data sets, communicating findings within an enterprise information system, and interactively browsing and editing databases using a direct manipulation paradigm instead of a form-based query system. (source http://www2.ilog.com/preview/Discovery/walkthrough/index.html).

3.3.1.2 ThinkMap SDK

ThinkMap's software development kit (SDK) (http://www.thinkmap.com/thinkmapsdk.jsp) includes components for visualizing data using either spider, hierarchy, clustering, or chronology visualizations. These pre-configured components can be customized using an XML-based configuration language. The SDK also allows plug-and-play connectors to JDBC databases, XML, and flat files, along with an API for integrating the Thinkmap SDK with non-standardized data sources and proprietary software.

In one example application, ThinkMap was used to create the Visual Thesaurus (http://www.thinkmap.com/visualthesaurus.jsp), a 3D interactive reference tool.

ThinkMap SDK is sold in three editions: Standard, Professional, and Enterprise. Prices start at $5,000, with educational discounts available. Enterprise editions come with the full source code.

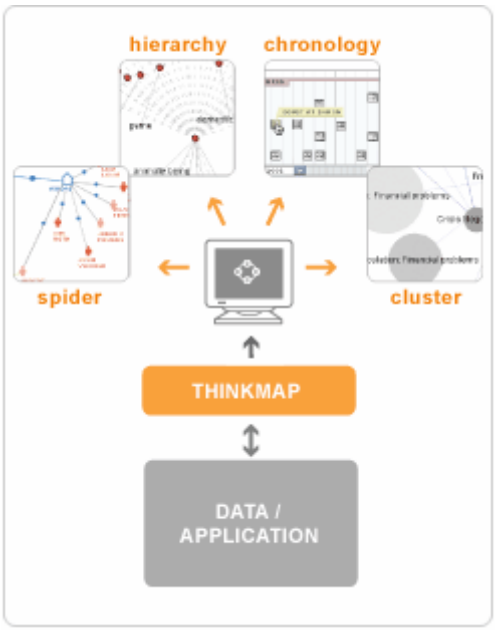


Figure 14. *ThinkMap SDK Architecture*
Components within ThinkMap's software development kit can be customized using an XML-based configuration language to work with non-standardized data sources and proprietary software. (source http://www.thinkmap.com/thinkmapsdk.jsp).

3.3.1.3 AVS/Express

AVS/Express (http://www.avs.com/software/soft_t/avsxps.html) is a graphical application development environment that provides powerful visualization methods applicable to fields such as science, business, engineering, medicine, telecommunications and environmental research. It contains objects, data structures and libraries specifically designed to analyze and visualize very large and complex datasets. Figure 15 shows an example application.

AVS/Express is targeted at scientific data visualization, and would support simulation, modeling and physical model display.

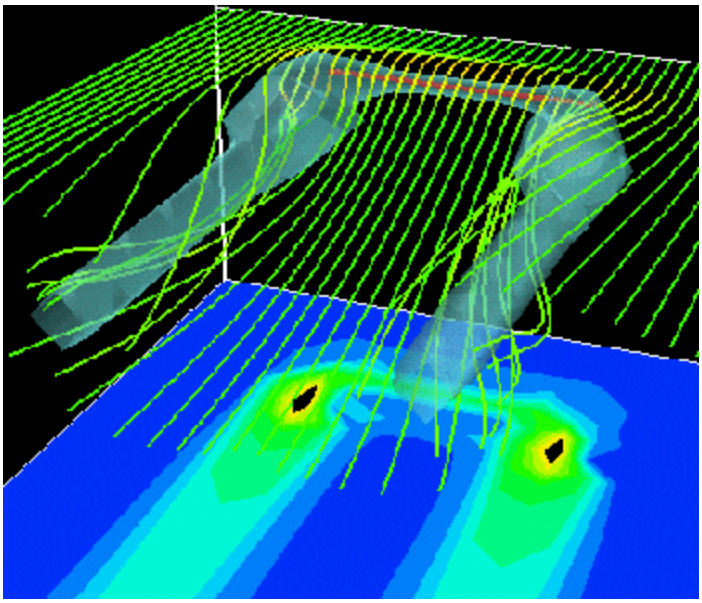


Figure 15. *Example AVS/Express Application*
In this example, AVS/Express was used to visualize the flow around a finite wing (source Iestyn Jowers, School of Engineering, University of Manchester http://www.iavsc.org/repository/express/pages/f-wing/image_f-wing.shtml).

3.3.1.4 InfoVis Toolkit

The InfoVis Toolkit (http://ivtk.sourceforge.net/) is a Java toolkit to provide interactive display of information. It is still in the beta stages with the last update being made in Nov, 2005. It provides the ability to create implements nine types of visualization: Scatter Plots, Time Series, Parallel Coordinates and Matrices for tables; Node-Link diagrams, Icicle trees and Treemaps for trees; Adjacency Matrices and Node-Link diagrams for graphs. Figure 16 shows a graph-matrix application.

The InfoVis Toolkit is distributed with source code and the license allows for inclusion into commercial products.

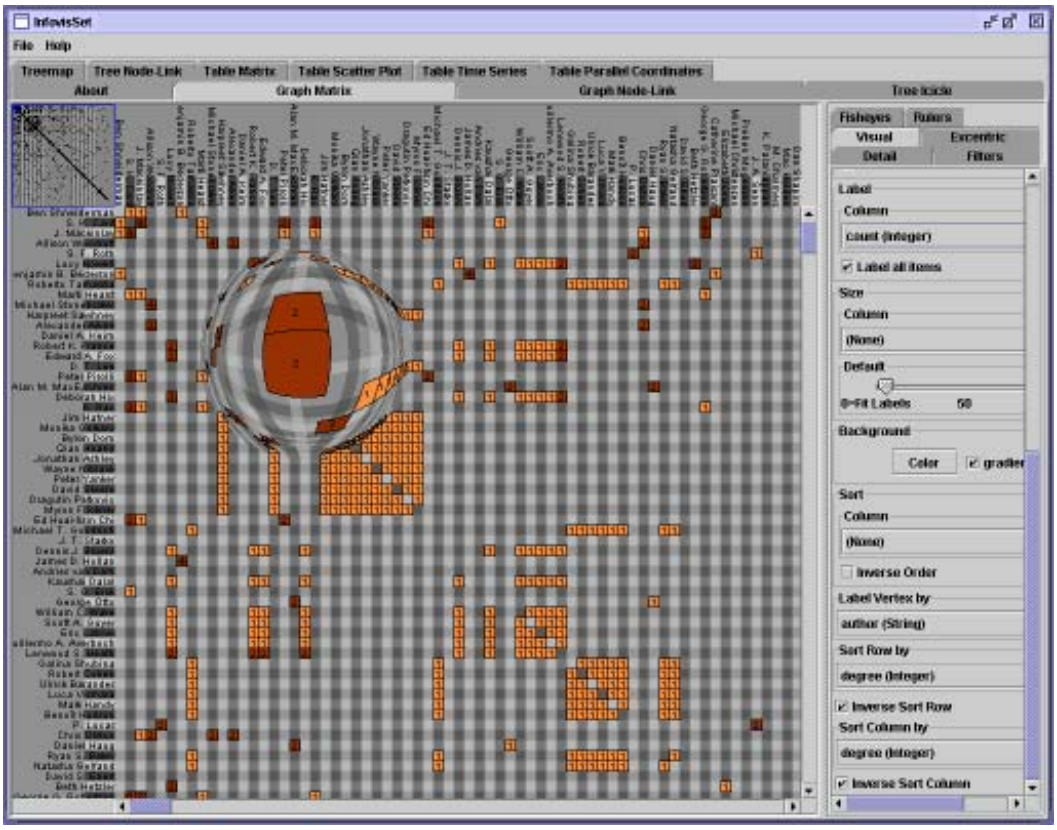


Figure 16. *InfoVis Toolkit Sample Application*
This screen shows a Fisheye lens on tabular data, displayed by the InfoVis Toolkit (source http://ivtk.sourceforge.net/GraphMatrix.png).

3.3.1.5 Oculus Development Kit

The Oculus Development Kit (http://www.oculusinfo.com/) is an SDK to allow for 2D/3D visualizations of business data. Made in Canada, it provides many operations (drawing shapes, data-driven tooltips, pointer-focus, animation, textures for objects) to enable the creation of visualization applications, such as the one shown in Figure 17. It is built on top of Microsoft DirectX and Direct3D. It provides efficient rendering of large data sets and supports sophisticated interactivity.

The Oculus Development kit comes in a .NET version and a Java version.

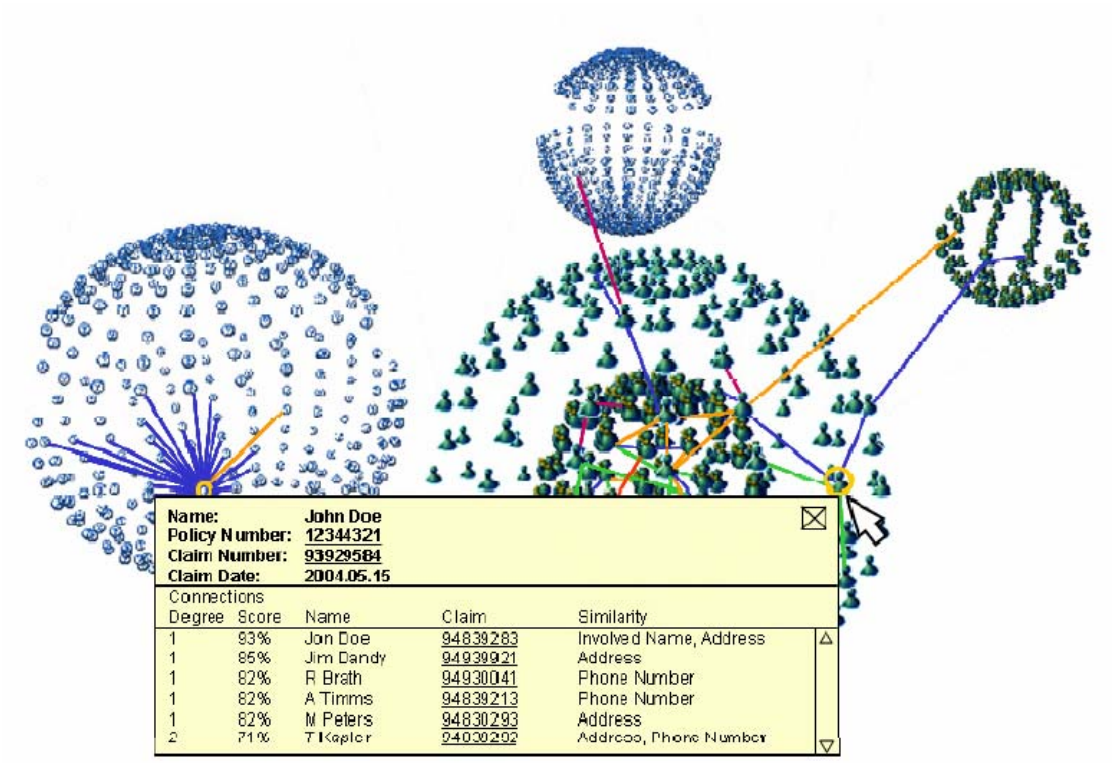


Figure 17. *Sample Oculus Application*
In this example, an Oculus visualization of potential fraud rings uses point and click to follow the linkages between suspect individuals and drilldown to record details (source http://www.oculusinfo.com/papers/OculusDotNet_Whitepaper.pdf).

3.3.1.6 PreFuse

Prefuse (http://prefuse.sourceforge.net/) is an open source toolkit written in Java that provides functions for creating data modeling, visualizing, and interactive applications. Prefuse provides the data structures (tables, graphs, trees) as well as various layouts and support for animation, such as the visualization in Figure 18.

Prefuse provides components for tables, graphs and trees as well as for layout, color, distortion and animation. It supports typical user interaction features common to information visualization tools such as zooming, panning, and overview and detail views. A unique feature is its integrated text searching using a number of available search engines.

Prefuse is licensed under the terms of a BSD license, and can be freely used for both commercial and non-commercial purposes.

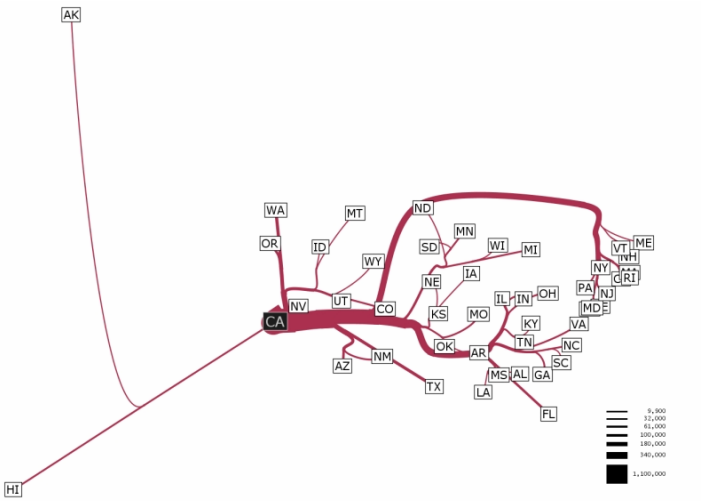


Figure 18. *Sample Prefuse Application*
This is a flow map of migration from California from 1995-2000, generated automatically by PreFuse (source http://prefuse.sourceforge.net/).

3.3.1.7 Starlight

The Starlight Information Visualization System (Starlight) has been developed by Pacific Northwest National Laboratory to be a forerunner for future information visualization systems. It couples advanced information modeling and management functionality with a visualization-oriented user interface. Although primarily a platform for conducting advanced visualization research, it is mature enough to be considered a functional information analysis tool. Starlight visualization tools employ a common XML-based information model capable of effectively capturing multiple types of relationships that may exist among information of disparate kinds.

Starlight uses the digital information model shown in Figure 19, which has been engineered to be:

- comprehensive: support many different relationship types
- flexible: support many different information types
- human-oriented: mimic the way humans naturally relate information.

Once data has been marked-up (using XML) into one of these formats, Starlight can be used to visualize a wide variety of relationship types, including discrete property (i.e., field/value pair) co-occurrences, free-text similarity, temporal relationships, parent-child associations, network relationships, and spatial (e.g., geospatial) relationships. Figure 20, for example, shows a visualization constructed in Starlight's "Information Space." Real-world geographies can also be used.

Relationship Type:	General Similarity	Explicit Reference	Field/Value Co-occurrence	Parent/Child	Spatial	Temporal
Model Type:	*Vector-space* 	*Network* 	*Multidimensional Index* 	*Hierarchical* 	*Spatial* 	*Ordinal Index*
Examples:	*Reports, articles, DB records*	*References & citations, hyperlinks*	*DB records, document metadata*	*File paths, taxonomies, IP addresses*	*Geolocations, CAD models*	*Event descriptions*

Figure 19. *Starlight Information Model*
Starlight recognizes and provides visualization tools for six primary relationship types. Once real-world data is translated into one of these forms, it can be co-visualized with all related data. (source http://starlight.pnl.gov/).

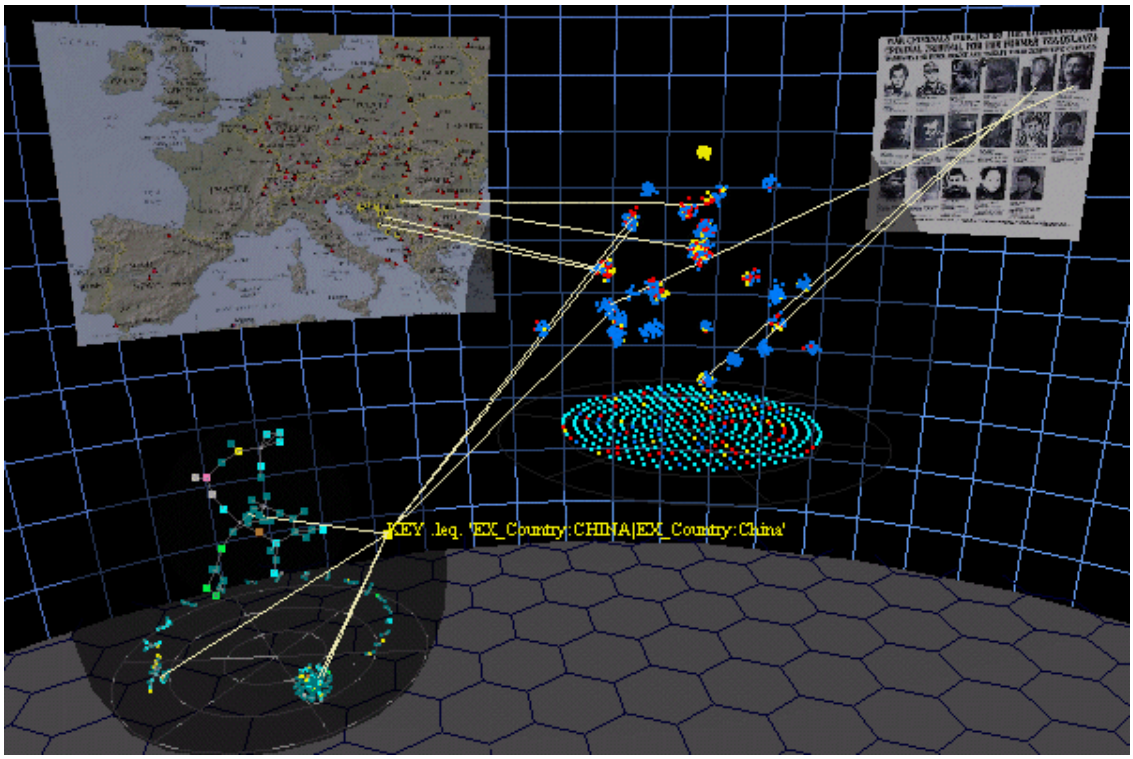


Figure 20. *Starlight Information Space*
Objects of a variety of types can be co-displayed within an abstract "Starlight Information Space" which is marked by the characteristic curved-grid rear wall and hexagonal deck. In this example, abstract relationships (e.g. telephone calls times and locations) are related to icons on a map and images in a most-wanted poster (source http://starlight.pnl.gov/).

3.3.2 Time Series

Visualization of time is important – users often want to understand how something has changed over time, whether it is terrain, numerical trends, intelligence cues, etc. The display of time can be static (e.g. CPU clock cycle increases over time), or dynamic (e.g. animated land erosion plots displaying terrain information 1 frame / year). This section focuses on manipulation and display of time series data. One could argue that all forms of visualization have the challenge of presenting change over time – this is different than visualization of time series data, although it is no less important.

These tools could be applied to various time-sensitive data. For example, it would be useful to highlight trends and anomalies regarding vessel traffic and shipping lane activity. These patterns could then be correlated to other intelligence-related information over time.

3.3.2.1 Browser

Browser (http://www.ncea.org.au/Browser/#2) is a data analysis tool designed for viewing time-series data (see Figure 21). Based on its supported file formats, Browser seems to be designed for agriculture data (rain fall amounts, soil erosion data, and runoff for example).

Browser allows data-series to be viewed separately or overlaid on top or above other series. Users can zoom into particular regions of charts or move through large data-sets using a variety of controls. Time series can be animated under mouse control. Another unique feature is its period-setter tool consisting of a timeline-like scrollbar (blue bar at the bottom of the display) allowing the user to change the viewing period, scroll through the data range or quickly jump to a particular period in the data range.

Development of the tool seems to have ceased since the last update was scheduled to be completed by 2004 and the website has not been updated since then.

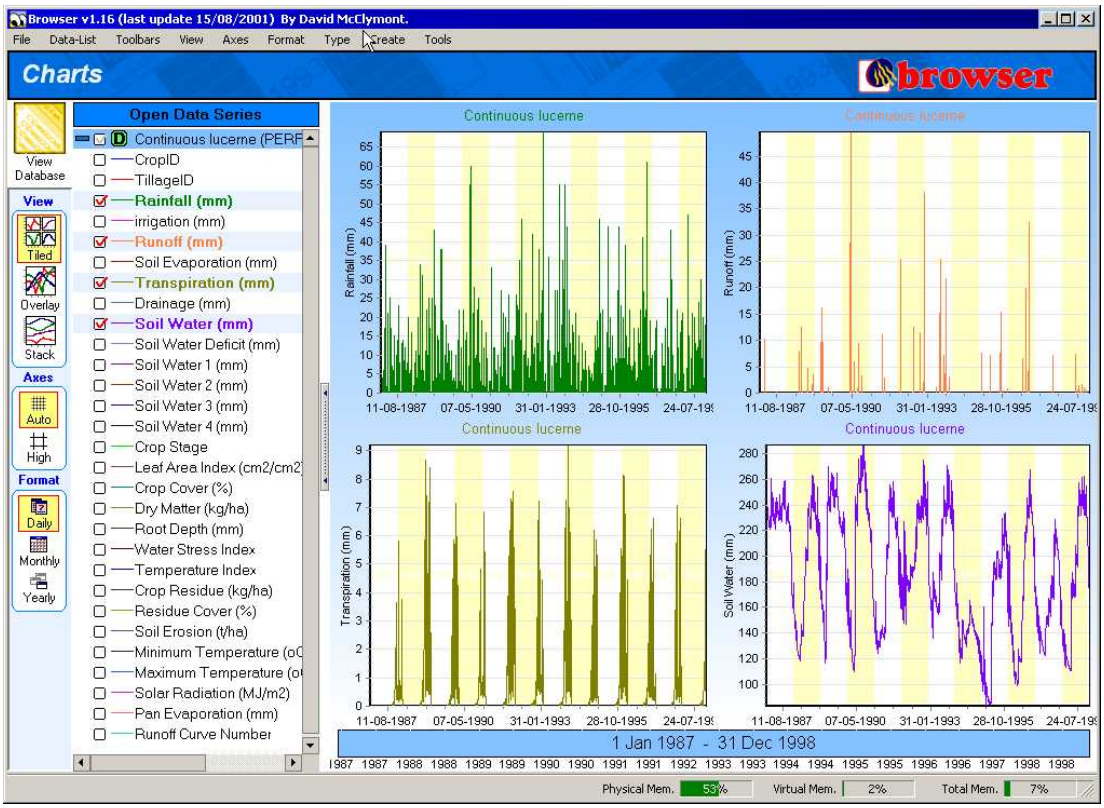


Figure 21. *"Browser" Visualization of Seasonal Rain and Runoff Data*
Browser was developed in Australia specifically to develop new visualizations for time-series data. (source http://starlight.pnl.gov/).

3.3.2.2 History flow

History Flow (http://www.research.ibm.com/history/) is a project created by IBMs Collaborative User Experience Research Group. It portrays the contributions and changes made by authors or communities on shared documents, in this case wikis. It provides a visualization of the dynamic, evolving documents and the interactions of multiple collaborating authors. This capability could be of interest in the intelligence field where updates to documents can be critical to the quality of the information, and many contributors may be involved in the final result.

This type of visualization could be used in a MISR system to help monitor changes made to a shared-intelligence system.

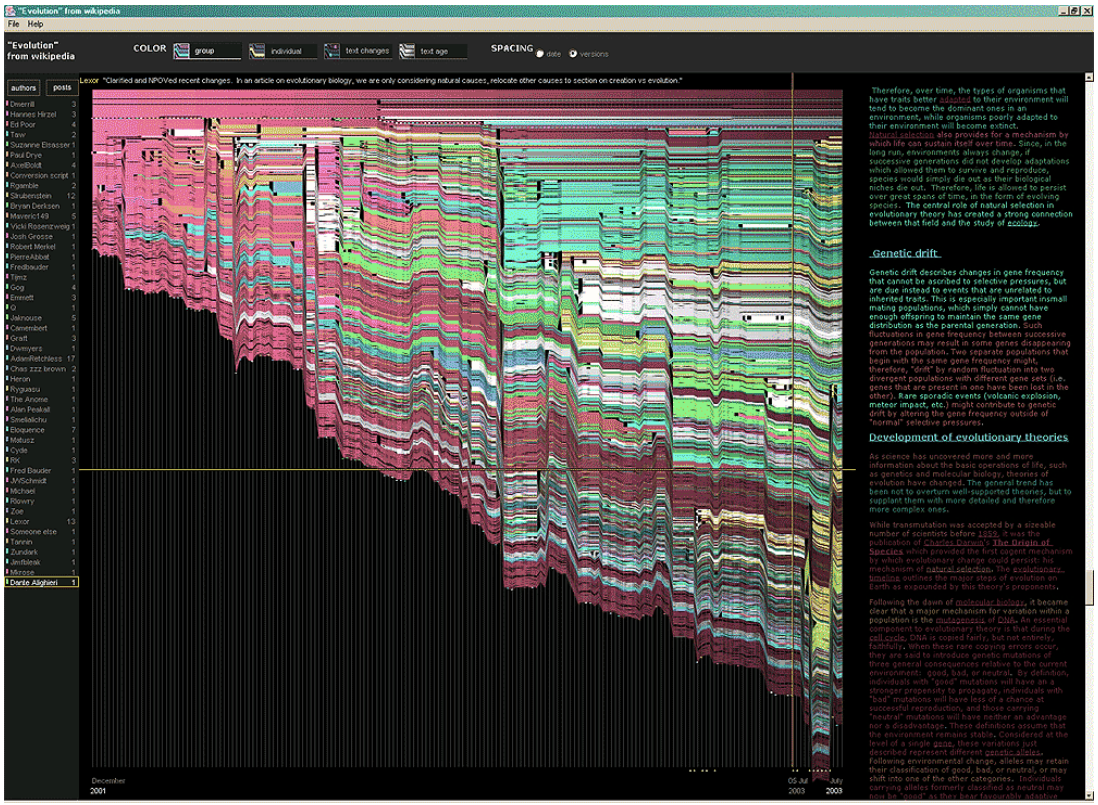


Figure 22. *History Flow Visualization of the Topic "Evolution" in Wikipedia*
The vertical axis portrays the length of the article, with contributions from each author marked in a specific colour. The horizontal axis is time. (source http://www.research.ibm.com/history/gallery.htm).

3.3.2.3 DataMontage

DataMontage (http://www.stottlerhenke.com/datamontage/) is a Java class library that enables the display information-dense collections of timelines, time-series graphs, and time-stamped notes within Java applets or applications. It provides the ability to stack graphs and timelines vertically or arrange them in rows and columns to see patterns spanning multiple variables, as shown in Figure 23. It also allows for control over the color, shape, and size of graph and timeline symbols lets you encode multiple attributes and highlight significant data points.

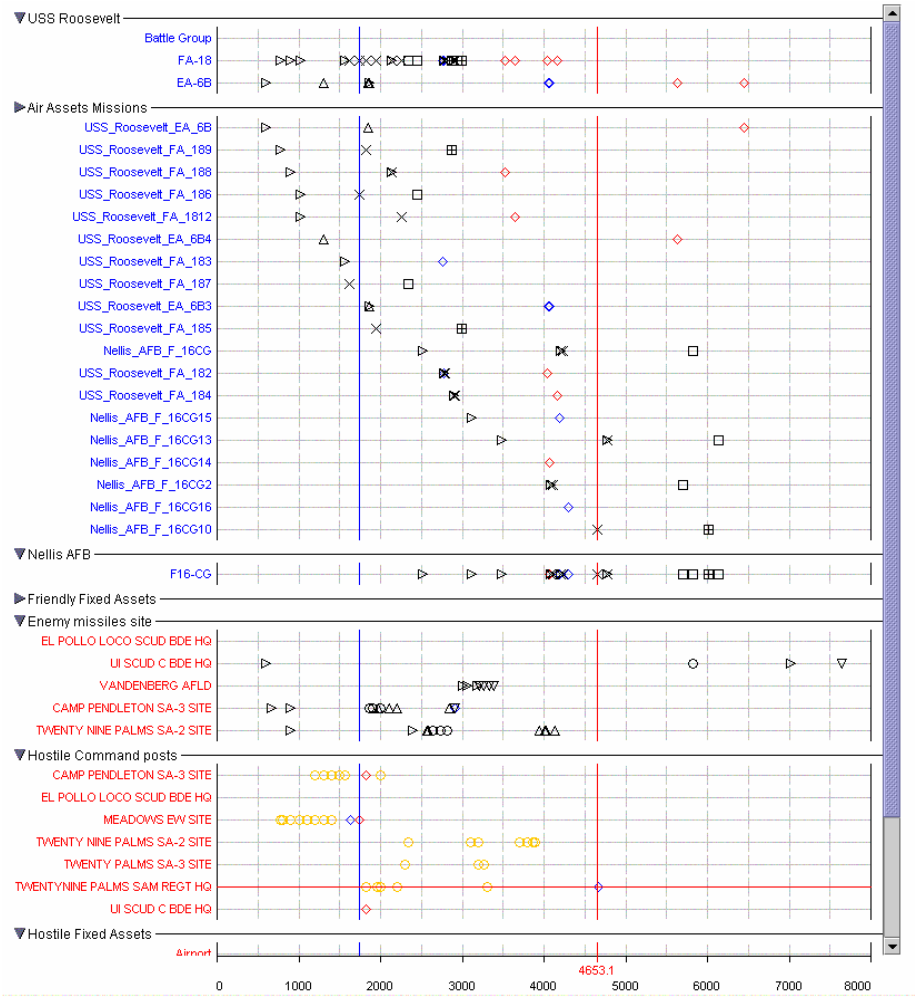


Figure 23. *DataMontage Airforce War Game Simulation Example*

This collection of timelines summarizes significant events that were generated by an experimental war-game simulation system. Simulation time in seconds is shown along the horizontal axis. Names of blue force assets are displayed in blue and names of red force assets are displayed in red. (source http://www.stottlerhenke.com/datamontage/examples/madcap/Air_force_wargame_simulation.htm).

3.3.3 Visualization Search Results

The following sections describe tools for visualizing the web and web searches.

3.3.3.1 Kartoo

Kartoo (http://www.kartoo.com/) is a visual meta-search engine created by KartOO Technologies (www.kartoo.net). Kartoo focuses on integrating information from various sources, and also attempts to cluster the information into logical groupings that can help the user in dealing with the large return result.

Kartoo takes the provided search terms and uses the results of many search engines to produce a map of the results, as shown in Figure 24. A map is a configurable number of search results sorted by relevance. In the map, the found sites are represented by more or less important size pages, depending on their estimated relevance. When the pointer is placed over these pages, the concerned keywords are illuminated, a brief description of the site appears on the left side of the screen and the links between the pages are displayed.

Figure 24. *Kartoo Search Results of "Information Visualization Research"*
Kartoo looks for link densities between sites, and plots the sites together with the most popular links.

3.3.3.2 GoogleBrowser

TouchGraph's GoogleBrowser (http://www.touchgraph.com/TGGoogleBrowser.html) provides a graph visualization of the search results of a Google "similar to" search. Linkages between information are critical, particularly when dealing with massive sets of knowledge and information. This tool tries to show the clusters of information, and also the linkages/dependencies between the information, as shown in Figure 25. In this way, the user is able to see the large groupings of information and look for adjacent topics and sources of information.

GoogleBrowser uses the link color to denote information about the links to the user. Dark gray edges indicate that the nodes at the endpoints are closely related and light gray that the relationship is looser. When a user moves the mouse over a node the gray edges are coloured blue and/or red. A red edge indicates that when one performs a Google similar search for the source site the target site will appear in the resulting similar page list. A blue edge indicates the reverse relationship. Both red and blue edges can be present simultaneously.

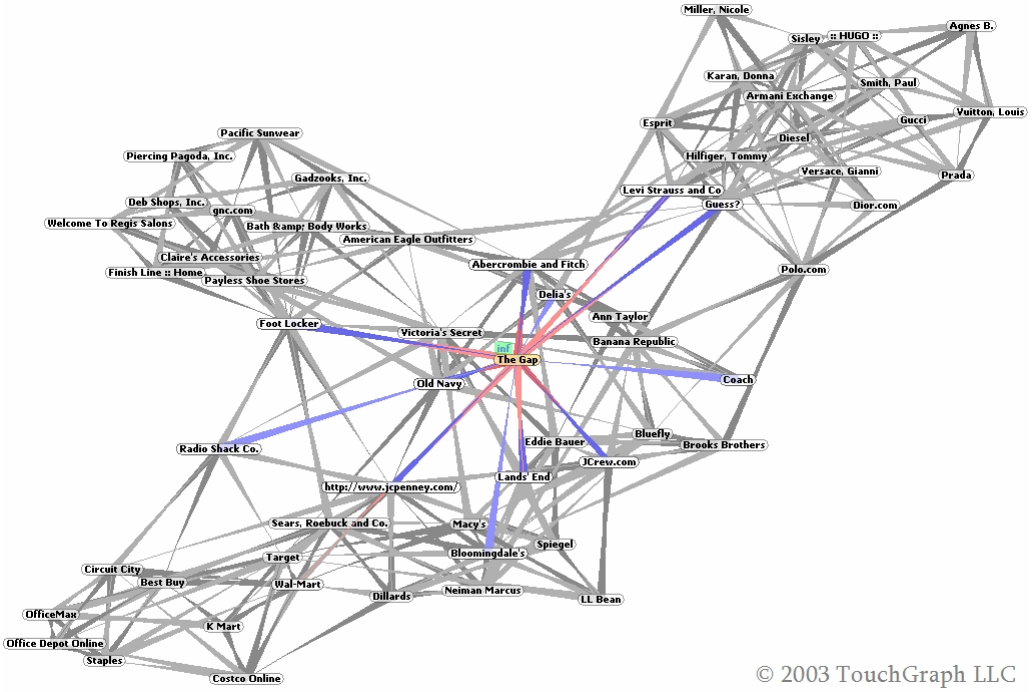


Figure 25. *TouchGraphs GoogleBrowser*
Googlebrowser plots links to sites that Google has identified as "Similar To" the current site. This can be extended to create a linked trail of websites. Clicking on a site highlights its links, as shown.

3.3.3.3 Web Brain

Web brain (http://www.webbrain.com/html/default_win.html) presents the results of a web search visually, as shown in Figure 26. Clicking on a topic will center the graph on the selection, with related topics branching out around the selected topic. Web sites that are related to the selected node of the graph appear at the bottom and selecting one of these sites opens it in a new window.

It is powered by TheBrain (http://www.thebrain.com/) technology.

Figure 26. *Web Brain Search Results on Information Visualization*

Web Brain provides a browser-like interface on the bottom, with an additional simple graphic on the top showing the web neighbourhood.

3.3.3.4 Grokker

The verb *grok* was invented by Robert A. Heinlein in his novel *Stranger in a Strange Land* (ISBN 0441790348), and defined as "to understand so thoroughly that the observer becomes a part of the observed—to merge, blend, intermarry, lose identity in group experience." Grokker (www.grokker.com) is a search map and overview applet that visually organizes the results of Yahoo and Wikipedia search results, but certainly falls short of its over-ambitious name.

Grokker provides more value-added information than Googlebrowser, for example. It organizes results by topic, as shown in Figure 27, and the operator can click on a topic to zooms into the circle and display the results at the next level in the hierarchy. The results are shown in the right pane. The left pane provides tools to allow filtering of the results by keyword, date, sources and domain.

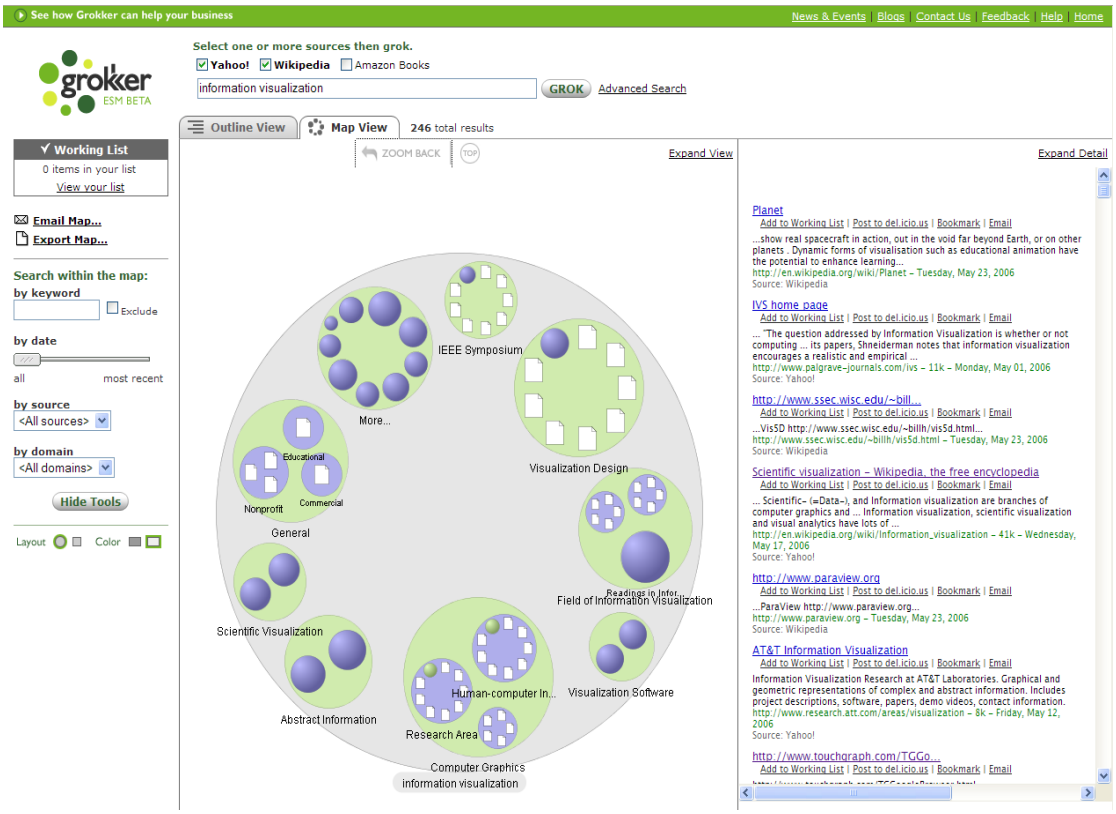


Figure 27. *Grokker results of searching for Information Visualization*
Grokker's map view provides advanced searches in the left pane, a clickable hierarchical neighbourhood in the center pane, and a classic search listing in the right pane.

3.3.4 Knowledge Visualization

Knowledge visualization encompasses a large body of research and development. One could argue that knowledge encompasses all information. However, knowledge visualization tools tend to focus on the management of information that has been derived from data.

3.3.4.1 Visual Thesaurus

The Visual Thesaurus (http://www.visualthesaurus.com/) was developed using the ThinkMap SDK. It is designed to help users find words through their semantic relationship with other words and meanings, by visualizing the network of the word and the similar words, as shown in Figure 28. As with the search results tools in Section 3.3.3, this makes it easier for users to start with something they know, navigate large amounts of information, and eventually find what they need without knowing exactly what the end goal is. The Visual Thesaurus also supplies additional information such as a suggested word list, dictionary meanings of the word, and a pronunciation of the word.

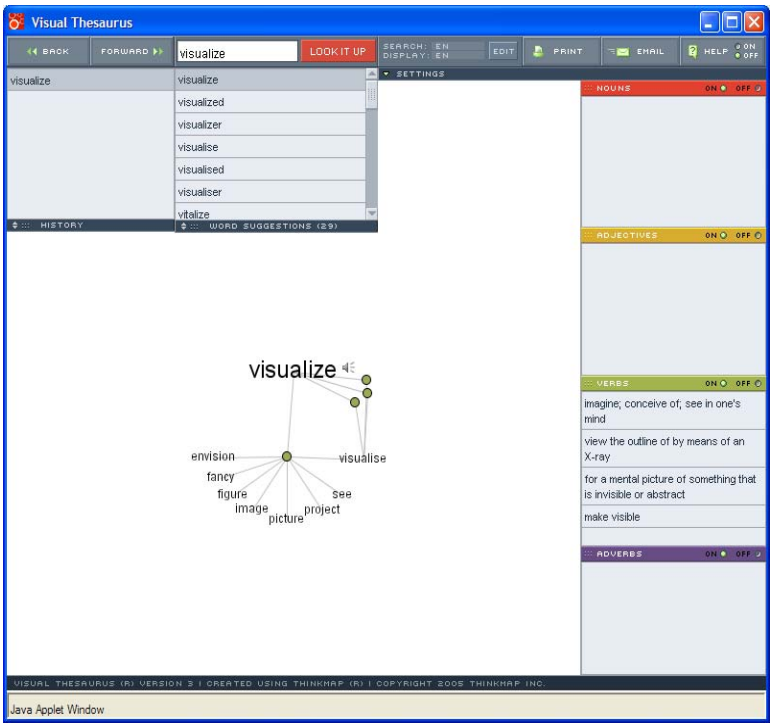


Figure 28. *Visual Thesaurus*
Associated words (synonyms) are shown schematically in the center, colour codes by the various senses of the word. Definitions are provided in the right hand column.

3.3.5 TreeMaps

Tree maps are not a new concept, but they are certainly one of the most important advances in the visualization of complex masses of information (textual or otherwise). There is good evidence to show that the brain decomposes and clusters information – this may explain the importance of tree and map technologies for managing information for human consumption. Many of the available treemap solutions are actually SDKs that enable companies to develop their own solutions.

TreeMaps are not trivial to develop, because the developer has to make decisions on how to display and group information. Typically, the challenge is in labelling portions of the tree, without making the text too small or too busy. The developers often use color and shading as additional visual cues, but text superposed on the map is critical, and can often be difficult to discern on a two dimensional display.

3.3.5.1 *Tree Map*

Treemap (http://www.cs.umd.edu/hcil/treemap/) is a software product created by the University of Maryland Human-Computer Interaction Lab that allows the development of Treemap applications, such as the one shown in Figure 29. Its goal is to break down and group information into manageable and readily interpreted clusters. The threshold for groupings and fidelity can be controlled by the user, and allows users to start at a "50,000 foot view" and zoom in on portions of the tree as they dive into lower levels of detail.

Treemap is available free for non-commercial use and can be licensed. The last update occurred in February 2004.

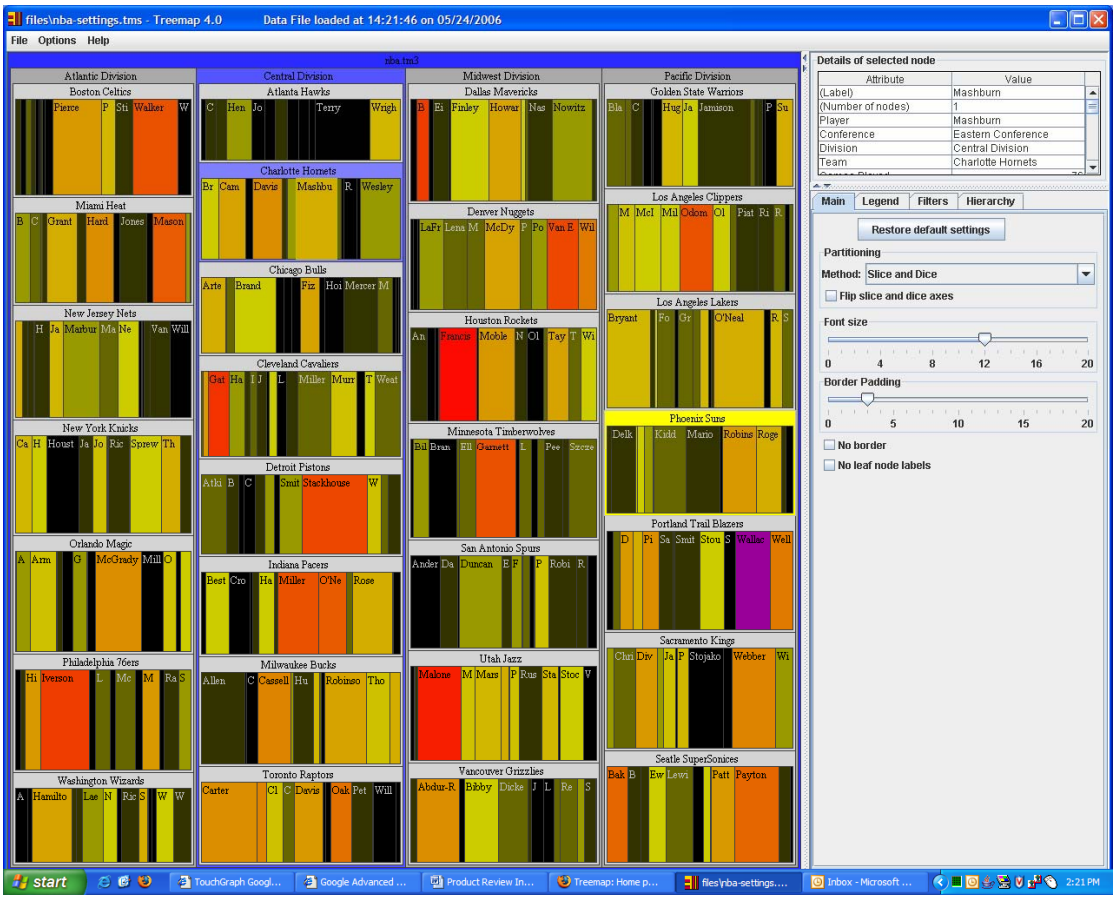


Figure 29. *Treemap Java Applet showing NBA Statistics*
This treemap was created using a Software Development Kit from the University of Maryland. (source http://www.cs.umd.edu/hcil/treemap/)

3.3.5.2 *HistoryWired*

"History Wired: A few of our favourite things" (http://historywired.si.edu/) is a treemap visualization program through which you can take a virtual tour of the collections of the National Museum of American History. Its innovation is in its ability to apply treemaps to a complex historical and timeline-dependent repository of knowledge. This is typically achieved in a large text document, with the user relying on text search features to find events of interest. Searching a time-arranged text document typically involves searching or scrolling through the document to zoom in on a period of interest. Treemaps can be used to group time and subject matter to simplify navigation and interpretation.

It provides a treemap of the museums collection, but also provides a time slider in which to filter the map to. The top blue bar provides an additional filter based on the selected theme(s). Once an item has been selected, its details appear in the left-hand pane.

The HistoryWired application was designed by SmartMoney.com using their "Map of the Market" technology.

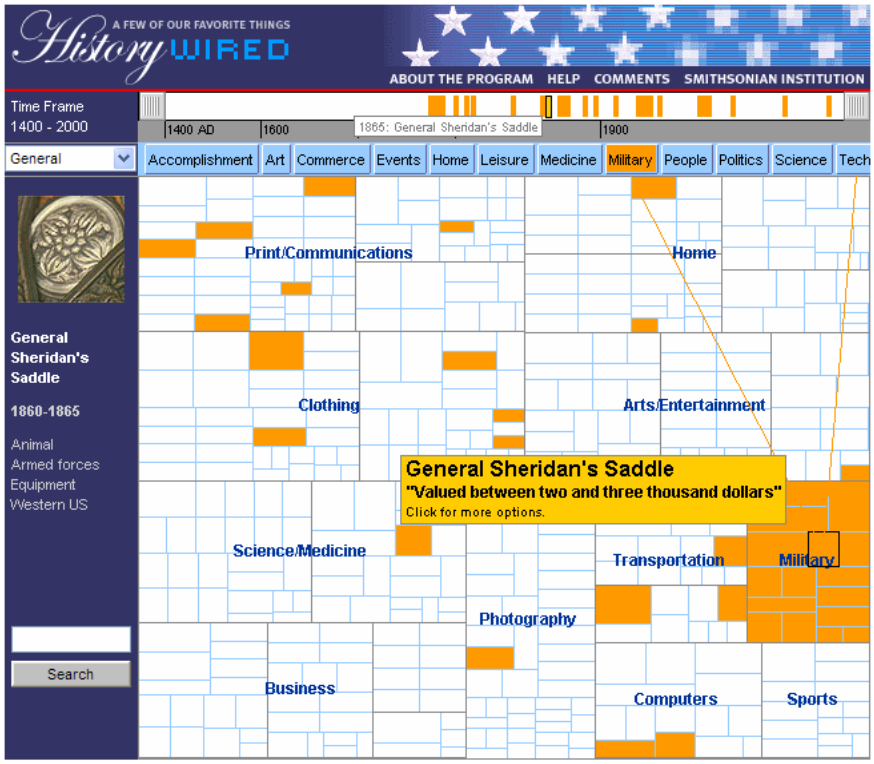


Figure 30. *HistoryWired with General Sheridan's Saddle selected*
This treemap provides a view of the museum collection, with a time slider to narrow the search. (source http://historywired.si.edu/)

3.3.5.3 SmartMoney

SmartMoney.com's Map of the Market (http://smartmoney.com/marketmap/) is a TreeMap that details the status of 500 stocks at once, as shown in Figure 31. It allows for drill-down to individual stocks and then provides access to details such as real-time quotes, and charts. This representation is interesting in that it has placed a bit more thought into the use of color and intensity to cluster information.

One possibility is that this type of map display could be modified to indicate urgency within the RMP, i.e. that similar shading and rules could be used to display priorities for investigating and dispositioning contacts and tracks within the RMP. This would provide the operator with some decision aids for prioritizing efforts based on various rules.

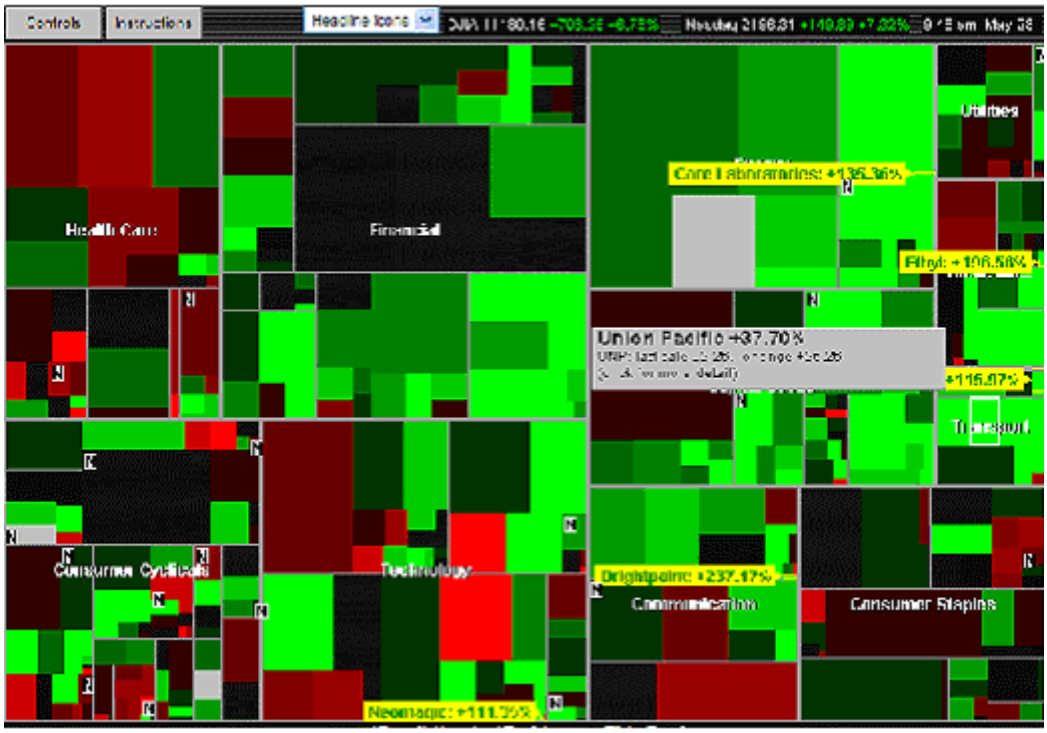


Figure 31. *SmartMoney.com's Map of the Market*
The colored rectangles in the map represent 500 individual companies. Each rectangle's size reflects the company's market cap and the color shows price performance: green means the stock price is up; red means it's down; dark colors are neutral. Viewers can move the mouse over a company rectangle to see a pop-up panel with more information. (source http://smartmoney.com/marketmap/instructions.html)

3.3.5.4 NewsMap

NewsMap (http://www.marumushi.com/apps/newsmap/newsmap.cfm) is a TreeMap display of the Google News news aggregator, and is used to visualize underlying patterns in news reporting across cultures and within news segments. It uses the Hive Group's (http://www.hivegroup.com/products.html) TreeMap product.

This tool is of particular interest because it provides a very rapid display of critical, current information, displaying headlines with sizes that reflect their popularity, as shown in Figure 32. The assumption is that more popular news is more important news. This tool also filters by subject matter so that users can filter news content based on International, domestic, sports or other subjects. This ensures that noisy news does not distract the reader. Many operation centers have a display dedicated to current news so that the operators are aware of any major events of significance that could affect their job. Rather than stay tuned on CNN, the NewsMap provides an effective and unobtrusive display of current events.

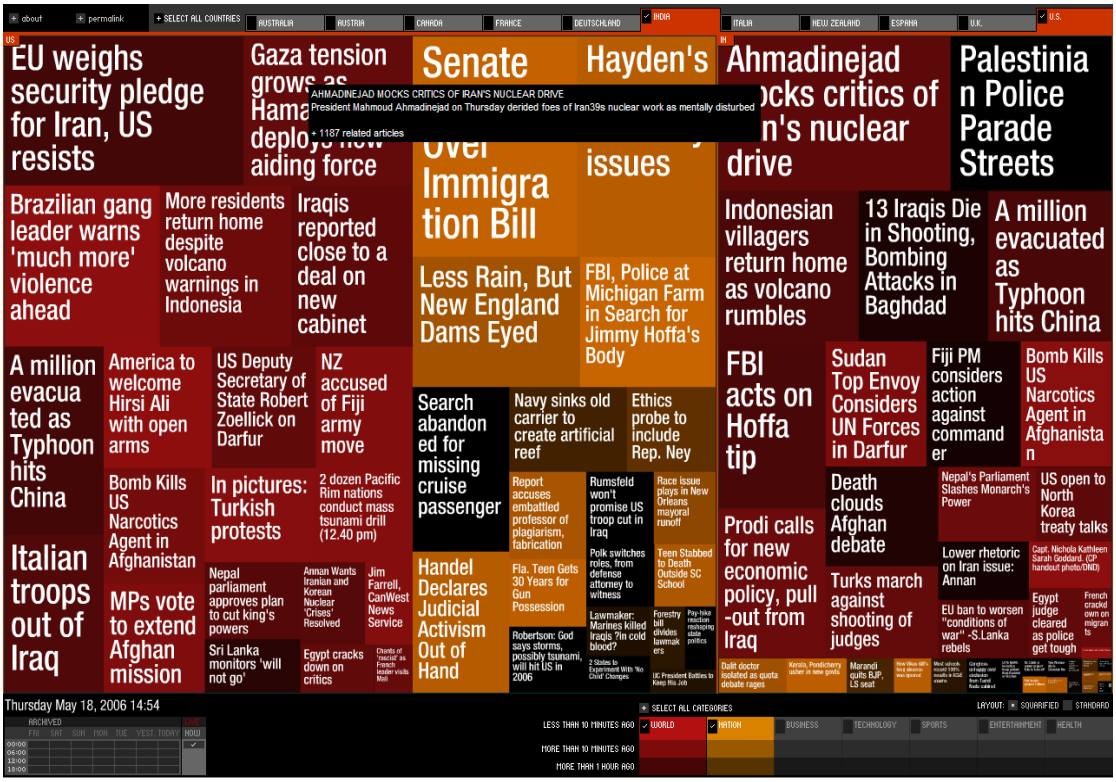


Figure 32. *NewsMap*
The tool displays the top-ranked headlines from many different news sources, and allocates treemap real estate according to how popular each topic is among the sources.
(source http://www.marumushi.com/apps/newsmap/newsmap.cfm)

3.3.6 Networks

Network visualization deals with problems similar to those handled by TreeMaps. Network maps tend to focus on portrayal of hierarchical information. Networks may or may not cluster, and there may not be a need to group information. Instead, the management of hierarchical and related information is provided.

3.3.6.1 Enronic

"Exploring Enron" (http://jheer.org/enron/) is a visual data mining research project by the Computer Science Department at UC Berkeley, using the archived emails of the Enron corporation. Exploring Enron is still in the preliminary stages, but it illustrates an interesting way to manage large inter-connected data sets. Email and other correspondence can result in large, unwieldy "threads" of discussion that are difficult to manage.

Enronic is built using the PreFuse library.

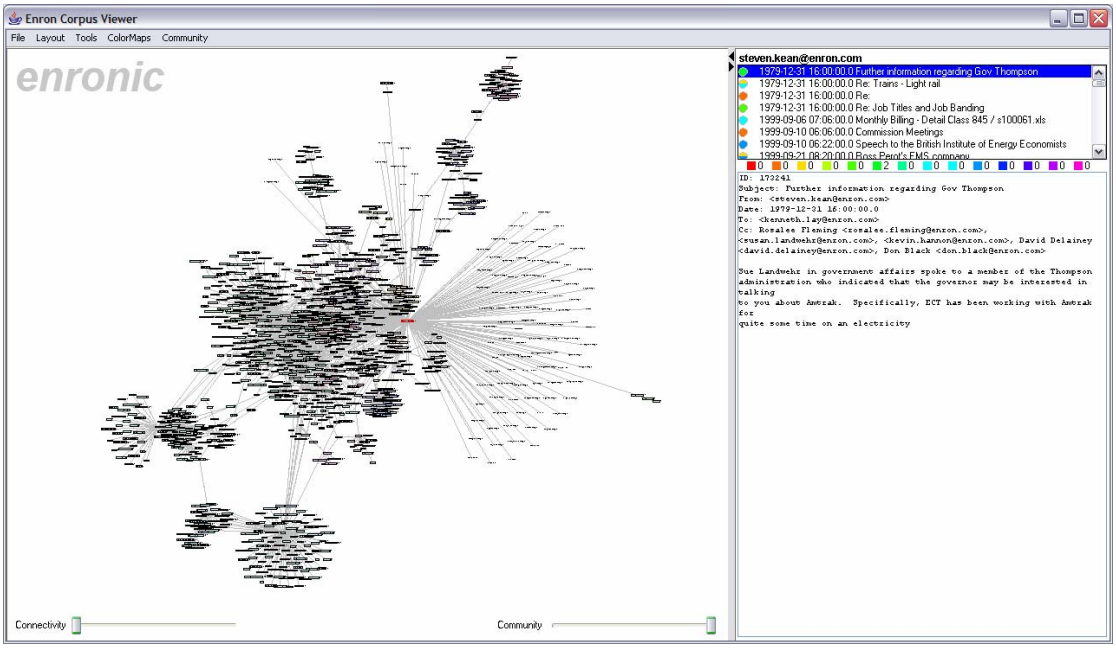


Figure 33. *"Exploring Enron" Visual Data Mining*
The graphic shows email threads, and email links between individuals.

3.3.6.2 *Visual Links*

Visual Links (http://www.visualanalytics.com/products/visualinks/index.cfm) is a Java product by Visual Analytics inc. that is used to discover patterns, trends, associations and hidden networks in data sources. It is used for analyzing networks of data, for example financial, criminal organizations, and intelligence.

The tool does provide various components which will alert users when new data is entered into the model, provide tools to automatically identify and correct ambiguous data, and a network miner that searches the data looking for relations between nodes.

The visualization aspects of the tool seem simplistic, as shown in Figure 34, and are only there to support the various data analyses components.

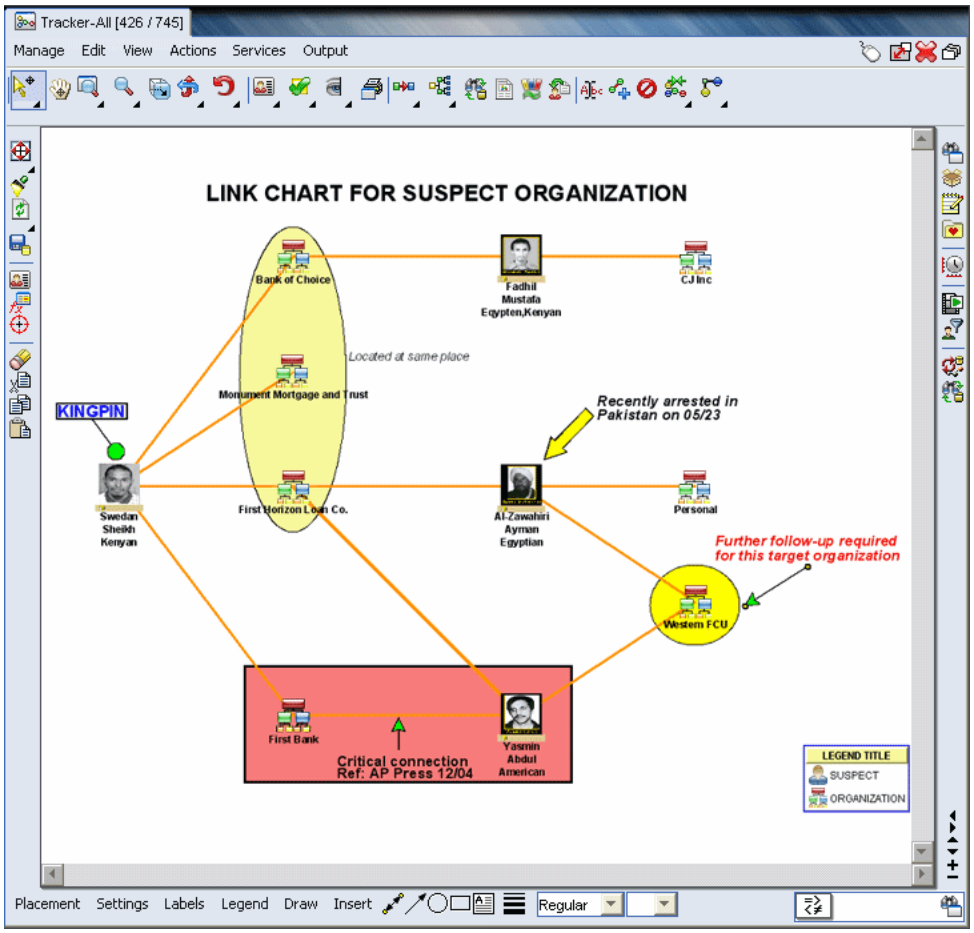


Figure 34. *Sample VisualLinks Application*
This example shows links between suspects in a criminal investigation.

3.3.6.3 Jung

The Java Universal Network/Graph Framework (JUNG) (http://jung.sourceforge.net/) is an open-source library that allows the modeling, analysis, and visualization of data as a graph or network, as shown in Figure 35. The JUNG architecture can represent directed and undirected graphs, multi-modal graphs, graphs with parallel edges, and hypergraphs. It provides a mechanism for annotating graphs, entities, and relations with metadata.

JUNG includes algorithms from graph theory, data mining, and social network analysis, such as routines for clustering, decomposition, optimization, random graph generation, as well as a visualization framework that allows developers to construct tools for the interactive exploration of network data using one of the layout algorithms provided, or use the framework to create their own custom layouts.

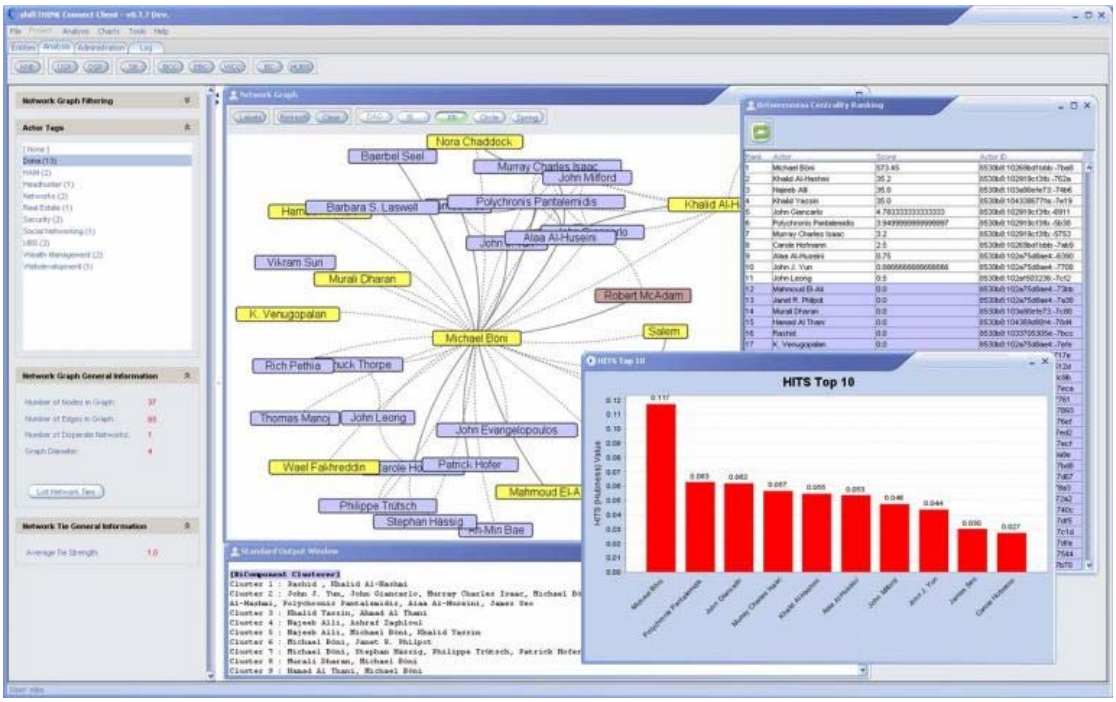


Figure 35. *Example Tool Written Using Jung*

shiftTHINK Connect (http://connect.shift-think.com/) is an application for the management and analysis of social networks written using JUNG.

3.3.7 Enterprise Knowledge

Large corporations accumulate massive amounts of information that is often underutilized because individuals don't know it is there, or are unable to easily benefit from the information. Entire companies have been formed to help assist enterprises with this challenge. These same technologies are also relevant to non-commercial interests, since government and academic organizations have similar problems. Typically these tools consist of a full enterprise architecture: display, services, agents, search and data management. These solutions can tie into various data sources (text, databases, web and other) to collect as much information as possible, then organize and link it such that it can be analyzed or otherwise levered by individuals.

3.3.7.1 *Spotfire DecisionSite*

Spotfire's DecisionSite (http://www.spotfire.com/) is an environment for analyzing data using interactive, data visualization, as shown in Figure 36, aimed primarily at a business management market. It has a developers API that allows for the development of custom applications. DecisionSite has recently been enhanced to integrate, analyze and visualize information from both text data mining tools as well as statistical tools.

DecisionSite now features "Guided Analytics™" which allows it to capture, as they happen, expert analytical processes for later reuse by other users.

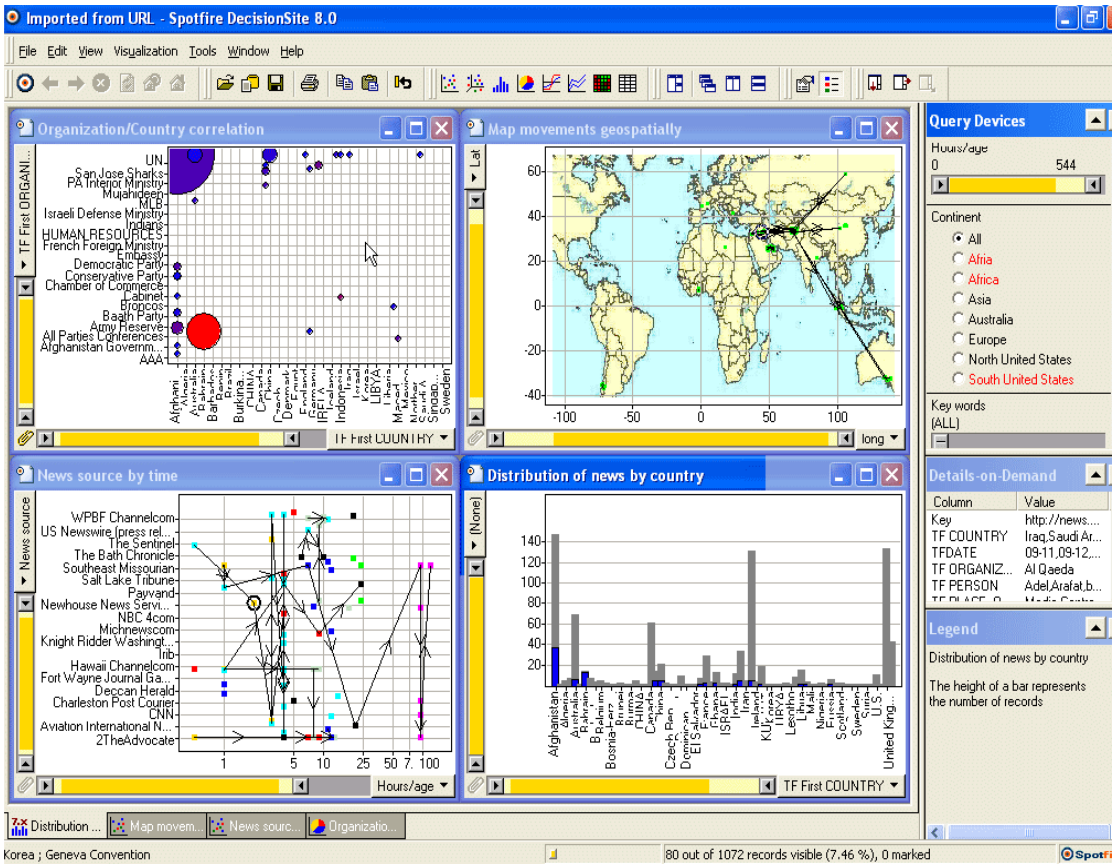


Figure 36. *Spotfire DecisionSite*

The DecisionSite environment can be automatically generated based on the imported data, without any programming, or it can capture and annotate an existing analysis workflow for use by others. Technical users can thus exchange best practices, while enabling non-experts to conduct their own data-driven guided analysis.

3.3.7.2 *Survey Visualizer*

Macrofocus's Survey Visualizer (http://www.macrofocus.com/public/products/surveyvisualizer.html) is a visual data mining application to access, analyze, and communicate the results from large and complex surveys (customer satisfaction, brand image, etc). All the results, at the different aggregation and grouping levels can be seen, examined and compared concurrently by the user, as shown in Figure 37.

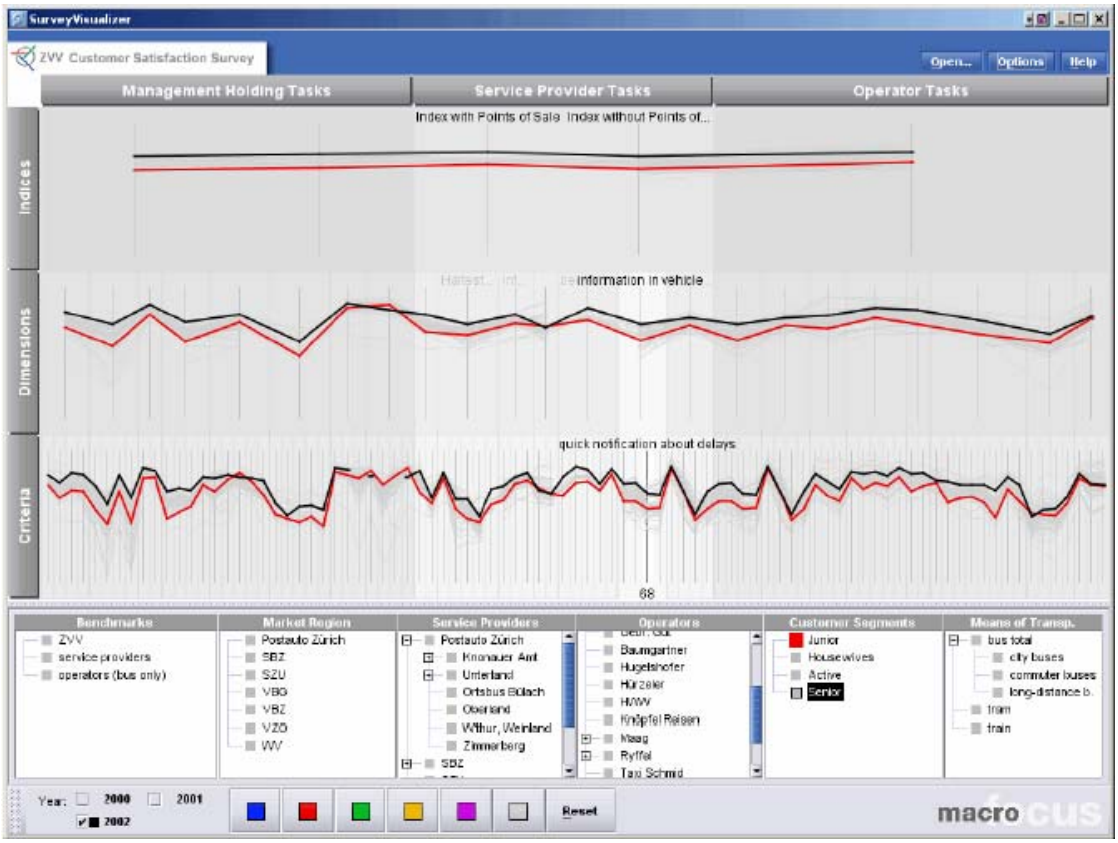


Figure 37. *Example Survey in Survey Visualizer*

The top window shows performance grades in a customer-satisfaction survey at three levels of coarseness, with associated metrics plotted above each other. The bottom window allows results from different customer groups to be overlaid in different colours. (Source http://www.macrofocus.com/public/publications/infovis2003/mainColumnParagraphs/00/document/infovis2003.pdf)

3.3.7.3 *InfoScope*

Another tool from Macrofocus is InfoScope, which includes a "Visual Attribute Explorer" tool as shown in Figure 38 (http://www.macrofocus.com/public/products/infoscope.html). InfoScope is an interactive visualization tool to access, explore, and communicate large or complex datasets. It is available free of charge from http://www.macrofocus.com/public/products/infoscope/download.html.

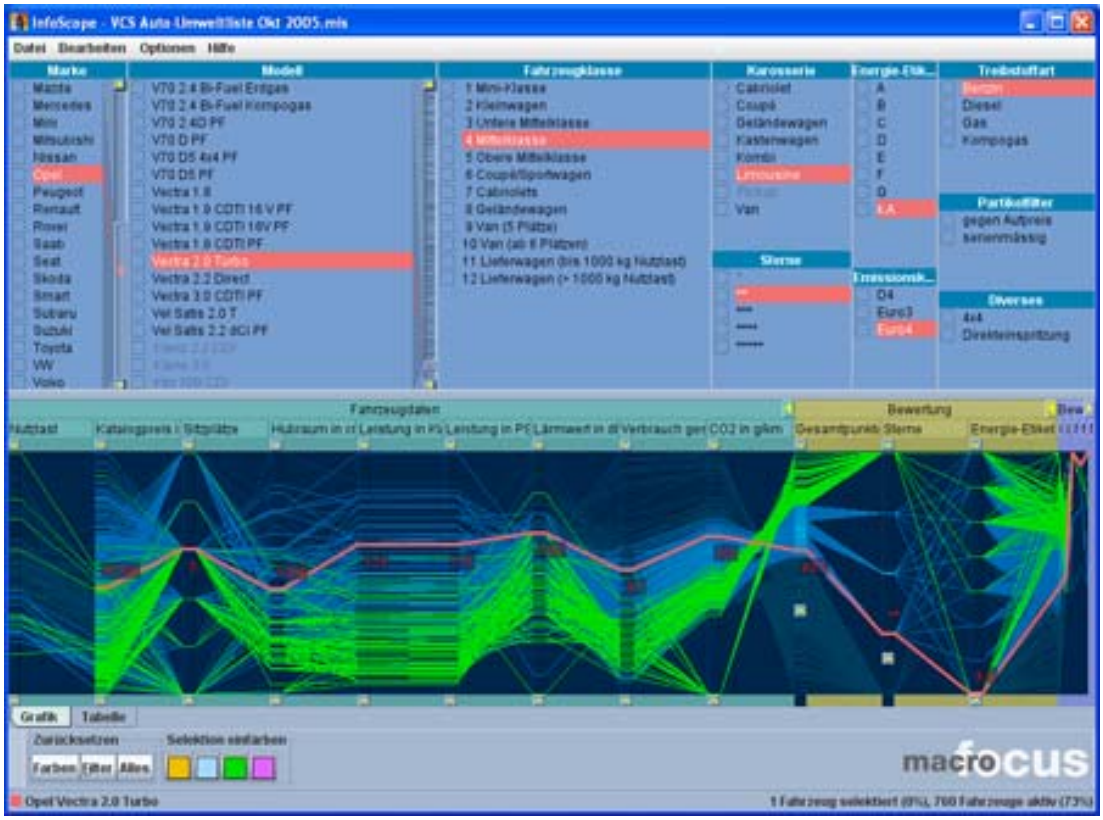


Figure 38. *Infoscope's Visual Attribute Explorer Tool*

Various attributes from various subsets of a dataset can be selected in the top window, and then co-displayed in the bottom window. Note the yell-coloured lens revealing more detail in the bottom-right corner. A detailed discussion is available at http://www.macrofocus.com/public/publications/cmv2003/mainColumnParagraphs/01/document/cmv2003.pdf.

3.3.7.4 IBM's Visual Attribute Explorer

IBM's Visual Attribute Explorer (http://www-128.ibm.com/developerworks/library/us-atex/) provides rapid data analysis through attribute bar charts and parallel coordinate plots. Using a bar chart view, the user may apply attribute constraints, and the influence of those constraints on other attributes may be assessed immediately. A separate parallel coordinate plot view allows further detailed analysis of the data.

Visual Attribute Explorer was last updated in October of 2003.

3.3.7.5 Data Mountain

Microsoft Research's Data Mountain (http://research.microsoft.com/adapt/datamountain/default.asp) allows users to place documents at arbitrary positions on an inclined plane in a 3D desktop virtual environment using a simple 2D inter-action technique, as shown in Figure 39. Data Mountain has been shown to have statistically reliable advantages over the Microsoft Internet Explorer Favourites mechanism for managing documents of interest in an information workspace; however, the lack of this features inclusion into any Windows product would seem to counteract these claims.

Data Mountain was developed in 1998 and no further work has been performed since then. Some use of 3D/2D combination seems to be integrated into the upcoming Vista release expected in the next year or thereabouts. For example, the three-dimensional folder and task display seems to incorporate some of these concepts.

Figure 39. *Microsoft's Data Mountain*
Microsoft explored new methods such as this for visualizing computer file hierarchies, but seems to have abandoned it.

3.3.7.6 SWAPit DocMiner

SWAPit Doc Miner (http://www.fit.fraunhofer.de/projekte/swapit/index_en.xml) is a text and data analysis tool that displays multiple views on text similarity, text categories, and associated relational attributes of text documents. Relationships between views are indicated by highlighting, as shown in Figure 40. SWAPit supports a variety of analysis tools including term and data statistics, searching and filtering, and information summarisation.

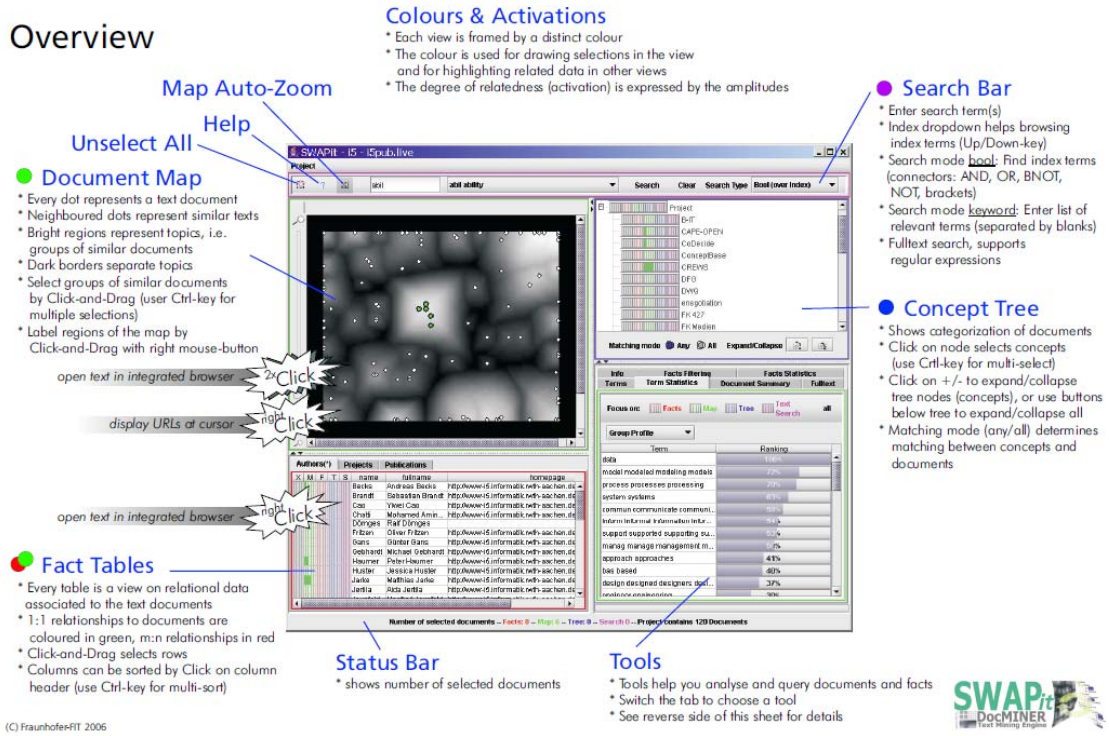


Figure 40. *SWAPit DocMINER Overview Page*

DocMiner provides extensive interactive tools for detecting patterns in large collections of documents. (source http://www.fit.fraunhofer.de/projekte/swapit/QuickGuideSwapitUI_en.pdf)

3.3.7.7 Autonomy

Autonomy's Visualization product, shown in Figure 41 and described at (http://www.autonomy.com/content/Products/Interfaces/Visualization.html), is designed to be used with Autonomy's IDOL Server. Autonomy focuses on data discovery, search and management.

The visualization tool provides various visualization techniques (2D, 3D clustering, Spectrograph and Result).

Figure 41. *Example Autonomy Result Visualization*

This tool provides some clustering and visualization capability that supports navigation of indexed but otherwise unstructured information.

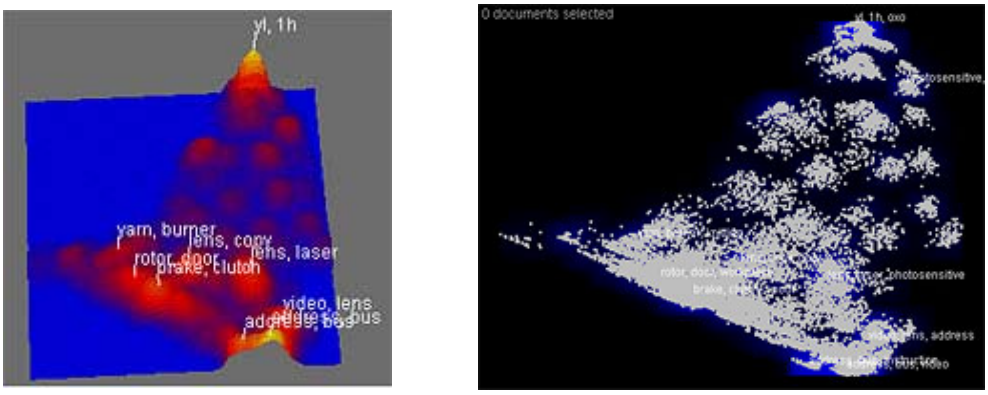
3.3.7.8 IN-SPIRE

IN-SPIRE (http://in-spire.pnl.gov/) is information visualization software developed by Pacific Northwest National Laboratory.

IN-SPIRE provides two visualizations of large sets of unformatted text documents, as shown in Figure 42:

- Galaxy Visualization – where grey dots represent documents and cluster around center points that represent central topics or themes.
- ThemeView™ Visualization - provides a visual overview of a collection of data. Users see a relief map where the highest peaks represent the most prevalent topics in the collection.

IN-SPIRE is also supplied with search tools that support simple queries, phrase queries, and queries with example text. Other tools help to explore trends over time and relationships between concepts.



(a) (b)

Figure 42. *Two Example In-Spire Views*
Image (a) is a ThemeView and image (b) is a Galaxy visualization.

3.3.8 Context and Depth

Users can easily suffer "information overload" when presented with too much information, or provided with a poorly designed display. Sometimes this problem is lessened by organizing the information better – how useful would a phone book be if it was not alphabetized? Another way to simplify management of large amounts of information is to allow the user to work at a "50,000 foot view" while providing further detail when directed by the user.

3.3.8.1 Fishnet

Fishnet (http://www.cs.umd.edu/~bongshin/projects/Fishnet/) is a web browser that incorporates a fisheye view so that it can always displays web pages in their entirety, as shown in Figure 43. Fishnet offers search-term highlighting, and assures that those terms are readable by using "popouts". This allows users to scan search results within the entire page without scrolling.

Figure 43. *Fishnet Browser*
This browser uses "popout" lenses to reveal details in a web page, while allowing users to view the entire page at once.

3.3.8.2 Piccolo

Piccolo (http://www.cs.umd.edu/hcil/piccolo/) is a toolkit developed by the HCI Lab of the University of Maryland that supports the development of 2D visualization programs. Piccolo provides implementations for functions such as such as screen repainting, bounds management, event handling and dispatch, determining which visual object the mouse is over, and animation.

It has been used to create many demonstration projects (approximately 20 on the UoM HCI pages alone) such as the one in Figure 44. There are currently three versions of the toolkit: Piccolo.Java, Piccolo.NET and PocketPiccolo.NET (for the .NET Compact Framework). Piccolo is open source and free for use. It was last updated in December 2005.

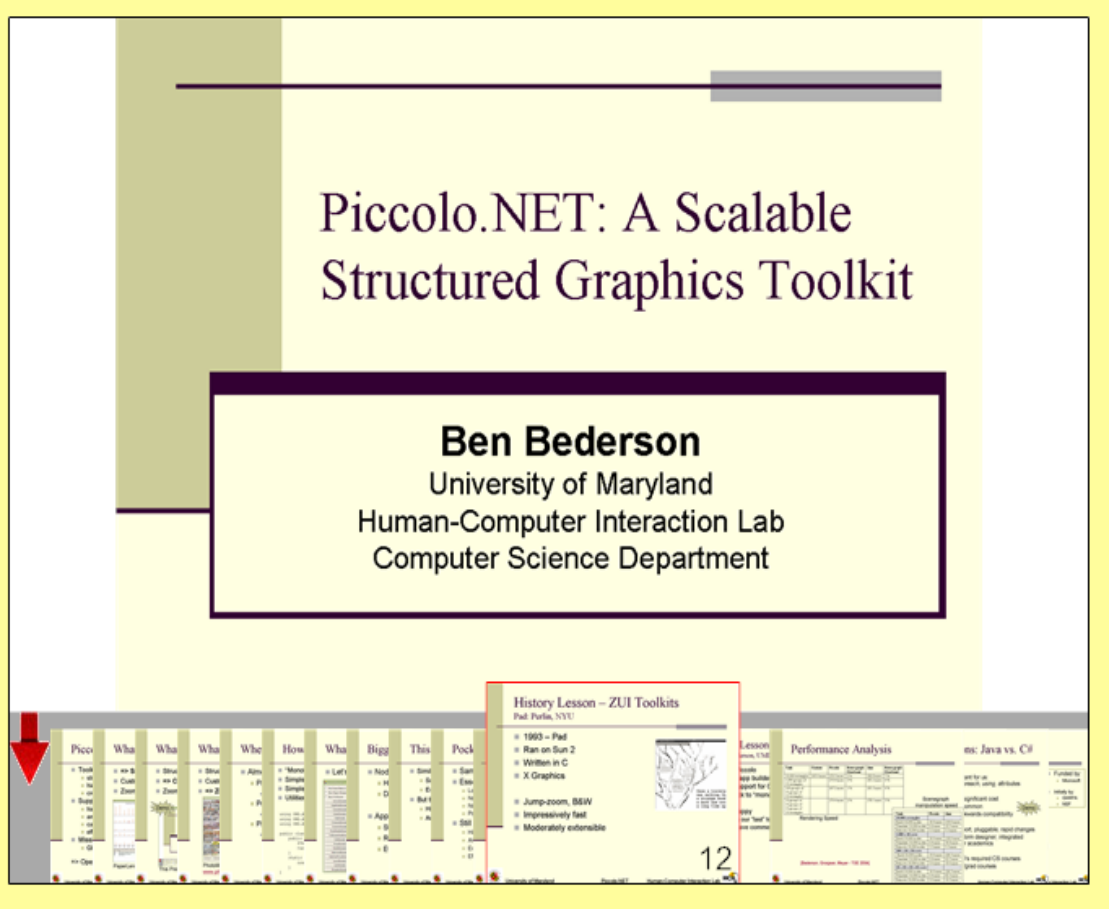


Figure 44. *Sample Application created using Piccolo.NET*
Piccolo provides a toolkit of interactive graphics visualization elements, such as the lens used here to reveal a postage-stamp view of Slide 12.

3.3.8.3 ZomIt

ZomIt (http://www.infres.enst.fr/net/zomit//index.html) is a generic package for developing zoomable user interfaces (ZUIs) that can aid in navigating large information spaces. Figure 45 shows a small Zomit-enabled zoom application.

Zomit includes navigation aids and an interaction model based on *Control Menus*. A control menu is a type of popup menu that is visually similar to a Pie Menu and makes it possible to select and control an operation in a single gesture.

ZomIt is written in Java. We do not know when it was last updated or the terms of its use.

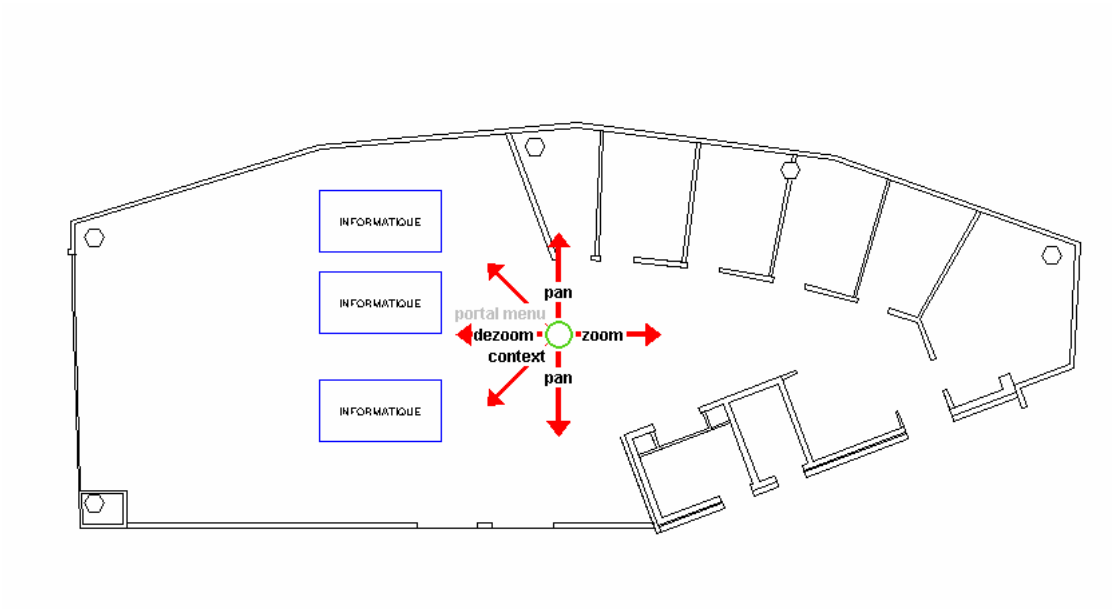


Figure 45. *ZomIt Sample Application*

Zomit is a low-level tool suitable for use in some visualization developments.

3.3.8.4 *Semantic Depth of Field (SDOF)*

Semantic Depth of Field (SDOF) (http://www.asgaard.tuwien.ac.at/sdof/index.html) is based on depth of field but instead of blurring objects based on their distance from the camera they are blurred based on their current relevance. This makes it possible to immediately see the objects being pointed out, and it can be used n two-dimensional objects such as pages of text, as shown in Figure 46.

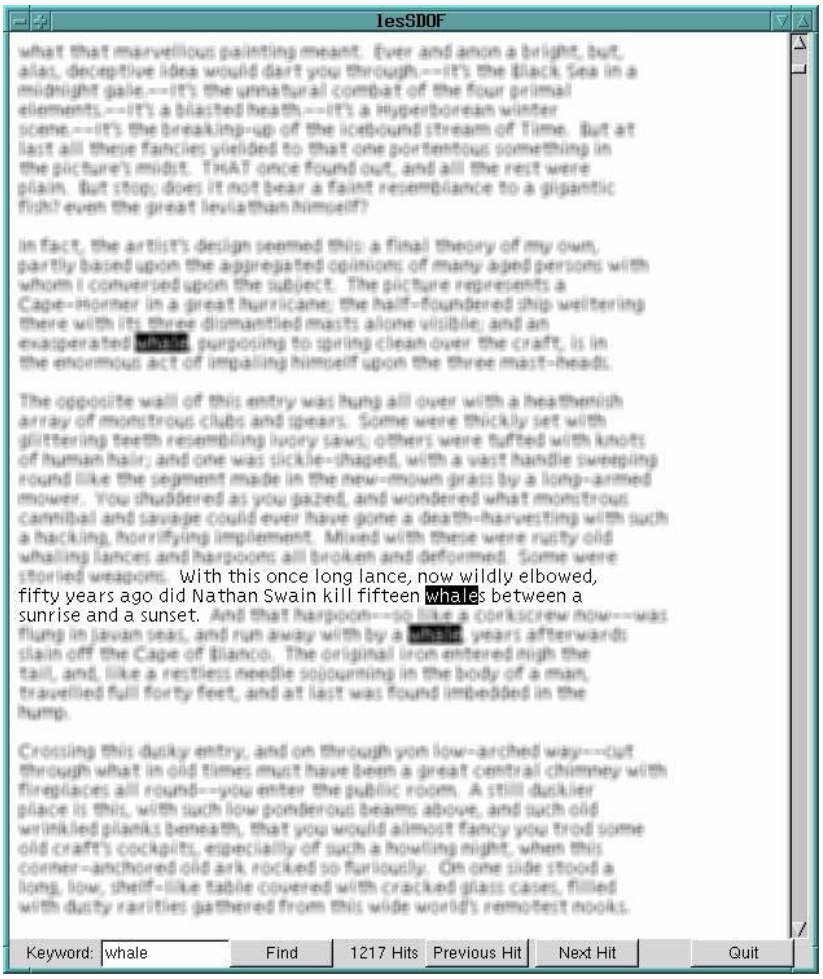


Figure 46. *Less Depth of Field (lessdof) Example Application*
In this lessdof example application search words are highlighted (as in most searches) but the sentence that contains the word is the only readable sentence on the page.

3.3.8.5 Visage

Visage (http://www.cs.cmu.edu/Groups/sage/visage.html) is a prototype software environment from Carnegie Mellon, for exploring and visualizing large amounts of diverse information. Figure 47 shows an example screen shot.

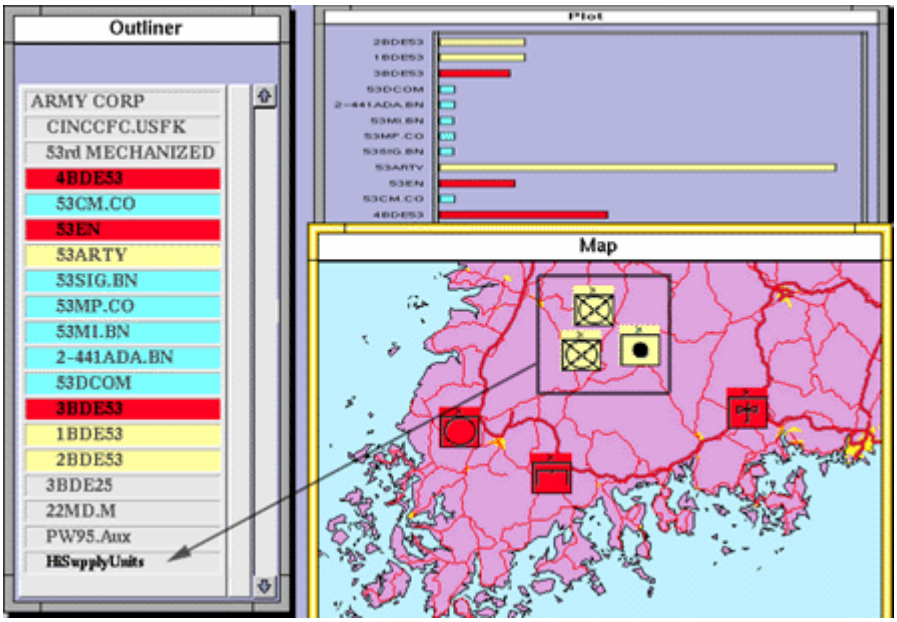


Figure 47. *Example Visage Screen*
Visage is a visualization research environment from Carnegie Mellon.

3.3.8.6 Stretch

Stretch (http://www.elastictech.com/) is a Java based application which provides a very fast exploration capability for hierarchies of tens of thousands of nodes. Its home page compares its performance to the Hyperbolic Browser. Figure 48 shows a demonstration screen.

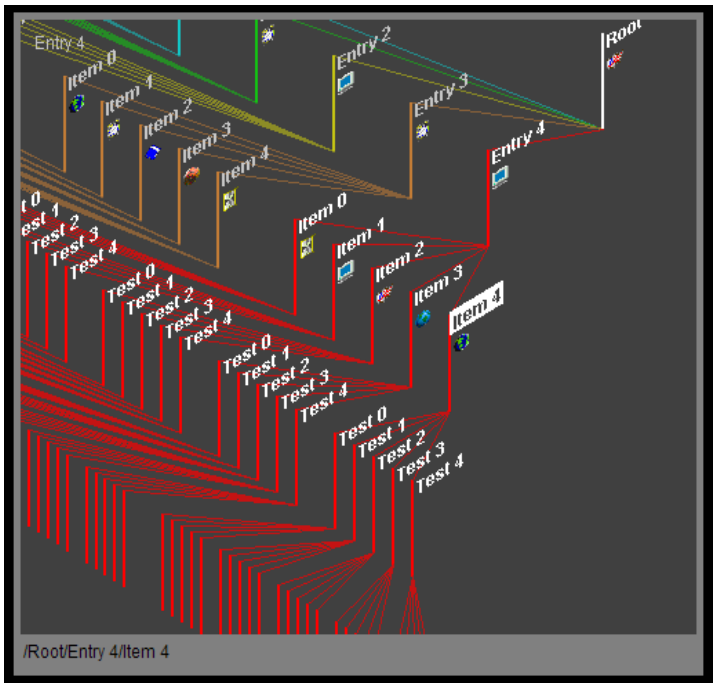


Figure 48. *Demo Screen for Stretch*

When an operator drags one of the labels up (for example "Item 4") other branches of the hierarchy (example the trees below "Entry 1" through "Entry 3") will smoothly fade into the background and the tree below Item 4 will expand and gain more detail. A user can thus explore a huge hierarchy very quickly. A very simple-to-use fully interactive demo of this capability is at http://www.elastictech.com/html/rand.html.

3.3.8.7 StarTree

StarTree® by Inxight (http://www.inxight.com/products/sdks/st/) allows for viewing a hierarchy of information or network relationships using a hyperbolic plane. It allows users to navigate large amounts of interconnected information while providing precedence and priority to information in the current context (at the center of the display).

Hierarchies are laid out in a uniform way on a hyperbolic plane, which is mapped onto a circular display region, as shown in Figure 49. Users can manipulate the focus by mouse clicks or dragging.

StarTree provides SDKs in either Java or .NET environments. These APIs give access to the full range of functionality of Inxight's StarTree technology for navigating and visualizing large hierarchies of information.

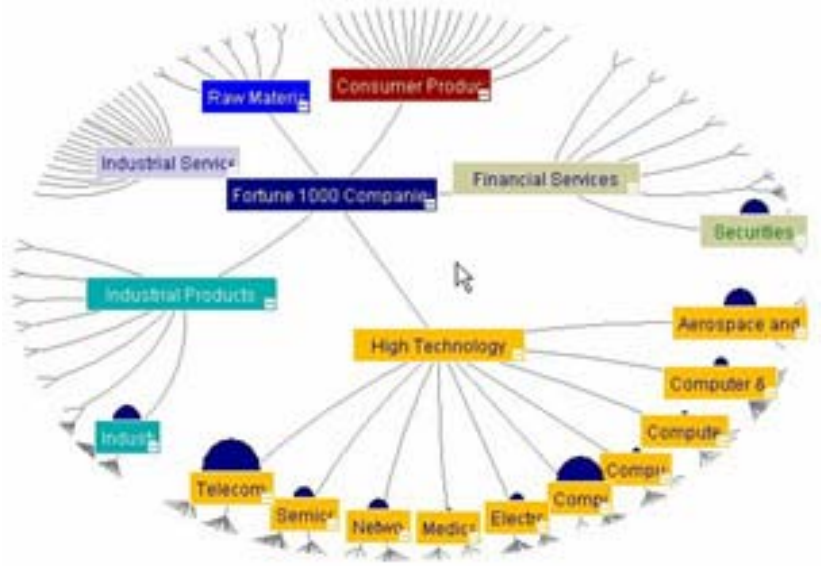


Figure 49. *Star Tree*
Star Tree uses hyperbolic maps to plot hierarchies. This provides better visualization of the first few levels of the hierarchy than a traditional vertical hierarchy.

3.3.8.8 TimeWall

TimeWall (http://www.inxight.com/products/sdks/tw/index.php) enables the visualization of patterns over long horizons while being able to focus in on a particular time of interest, as shown in Figure 50.

Filters allow the narrowing down of information based on any combination of structured information such as numeric, geographic, categoric, or other criteria.

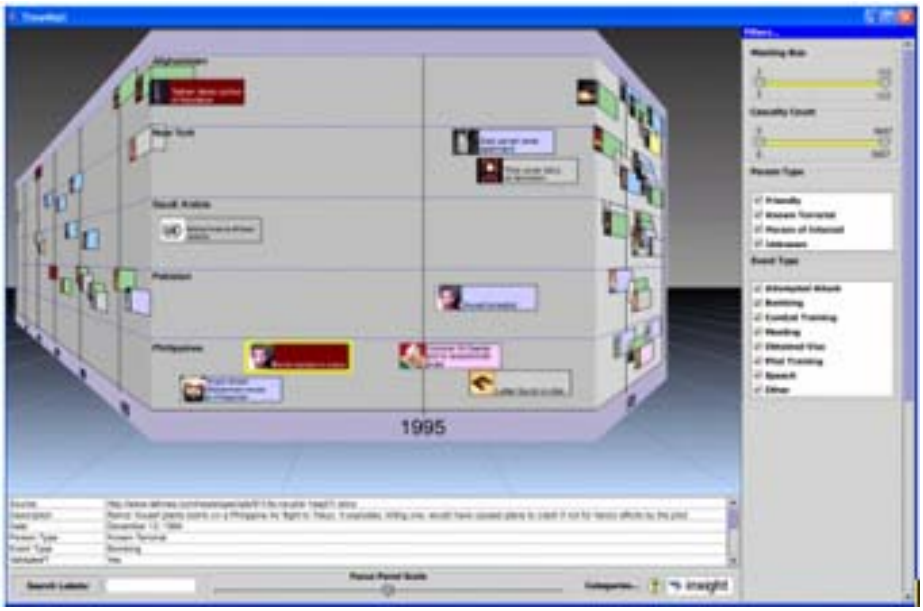


Figure 50. *TimeWall*
The time wall provides a detailed view of one point in a long series of data (a time series for example) while maintaining some context and view of the whole series. The user can drag the point being viewed.

3.3.8.9 TableLens

TableLens™ (http://www.inxight.com/products/sdks/tl/) visualizes large amounts of tabular data at once, enabling trends in data to be spotted. It displays records in columns and rows, as shown in Figure 51, and fills the cells with scaled and coloured horizontal bars instead of numbers. This allows very large data sets to be viewed without scrollbars, and without obscuring any data points. When details are needed, TableLens provides a magnifying lens. Columns can be re-sorted, grouped, and spotlighted. This enables the identification of trends, correlations and outliers.

Figure 51. *TableLens*
Vertical columns are graphical plots or histograms of a very large dataset (in this case major league baseball statistics) that can be examined in detail or resorted according to various criteria.

3.3.8.10 Pliable Display Technology

IDELIX's is a Canadian company whose Pliable Display Technology (PDT) (http://www.idelix.com) is directly aimed at military surveillance applications. Their PDT Software Development Kit (SDK) provides users with a "magic lens" detail-in-context viewing ability, as shown in Figure 52. Unlike a traditional magnifying glass tool used in image applications, PDT presents a magnified view of the area being examined, but distorts the surrounding areas to ensure that no points are hidden from the user. IDELIX is experimenting with sophisticated lenses that automatically conform to edges, for example, to aid in surveillance of perimeters. Versions of the PDT are also available where an analyst can edit the image (for example by adding annotations or mark-ups) through the lens.

PDT is available as a C++ and Java SDK for integration into applications

Figure 52. *Example of IDELIX's Pliable Display Technology*
In this image, the PDT tool provides a wide view of a very large image, with a zoomed-in view of the aircraft in the center-right. The zoom lens is dragged with the mouse, and can be customized to have different degrees of zoom and different shapes.

3.3.9 Linking Knowledge to Spatial Data

It is sometimes useful to assign geographical "tags" to knowledge information. For example, search engines add locale to web pages to support translation and localized search features. Some knowledge benefits from spatial context – a few tools are highlighted in this section to show different approaches to this problem.

3.3.9.1 OmniScope

OmniScope (http://www.iokio.com/omniscope/) is a Java application and publishing medium for visualizing, analyzing and filtering data and media, as shown in Figure 53. A key feature is that visualizations can be constructed using links to multiple spreadsheets and databases, and the visual presentations will be automatically updated as the data changes.

Figure 53. *OmniScope Displaying UN and CIA statistics*

Users can zoom in as far as they want without loss in picture quality. Multiple layers can show and hide features such as roads, towns and physical relief with a mouse click. A single mouse click creates markers on the map, inserting coordinates in latitude and longitude and creating records you can annotate with data, images and documents.

3.3.9.2 Oculus GeoTime™

Oculus GeoTime (http://www.oculusinfo.com/papers/GeoTime_Brochure_06.pdf) visualizes the inter-connectedness of evidence over time and space within a single, highly interactive 3D view. This time-enabled environment allows analysts to see patterns of behaviour and relationships in ways expressly aimed at military surveillance applications. GeoTime lets analysts track targets, see movement, show communications, understand sequence, and visualize cause and effect, as shown in Figure 54. Features include:

- Rich and flexible object model enables the separation, representation and analysis of events, event types, targets and places.
- Efficient tools for controlling and focusing the display to reveal patterns in time and space among many interconnected and moving targets.

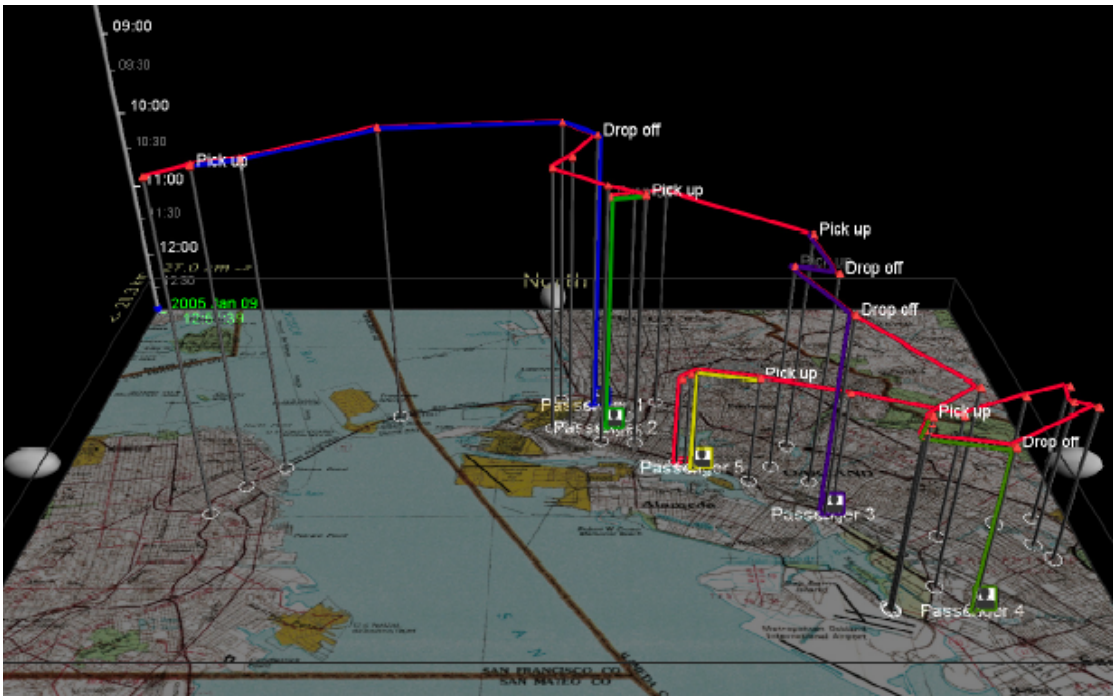


Figure 54. *GeoTime showing Target Trails*
GeoTime plots tracks as a typical GIS, but uses the z-axis as a timeline. The length of the line is the distance traveled while the slope of the line is the average speed of the track.

3.3.9.3 Center for Environmental Visualization Blue Engine

The Center for Environmental Visualization (CEV) at the University of Washington (http://www.cev.washington.edu/lc/CEVSV/pom_currents.jpg) specializes in visualizations of oceanographic and bathymetric data, such as that shown in Figure 55. The CEV has developed a "Blue Engine" graphics engine that specializes in presentation of earth science data within 3-D and 4-D applications. The CEV blue engine is currently being used within the Marine Exploration Games project and the BlueSpace project where the Java 3D visualization engine had previously been used. Blue Engine is built with open products that permit delivery to Windows, Linux, and Mac OSX based machines.

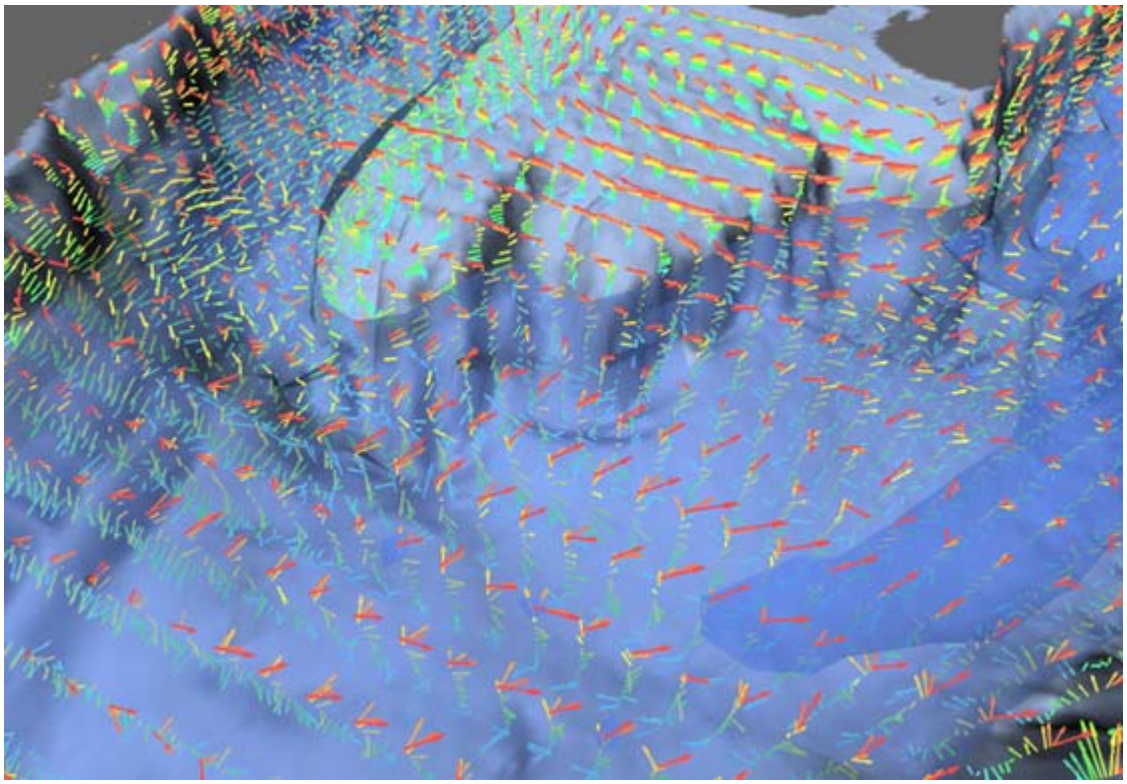


Figure 55. *Example METOC Visualization from CEV*
This image shows currents, salinity, and bathymetry in Puget sound. Currents are coded as small arrows, ranging from red for the shallowest to cyan for the deepest. Salinity is codes in the shades of blue, and bathymetry in the number of arrow at each point. (source http://www.cev.washington.edu/lc/CEVSV/pom_currents.jpg)

3.3.10 OLAP and Data Mining

On-Line Analytical Processing (OLAP) and data mining visualizations have been available for many years – manually before computers, and assisted by databases and cheaper software development technologies. These tools help the user to manage, visualize and sift through large amounts of information performing ad hoc queries or "what if" analyses. Some of these tools exist at a very simple and affordable level (e.g. Excel pivot tables), whereas other tools are targeted at high-end applications in large organizations.

OLAP and data mining provide tools for trend analysis, supporting operators in their decision and discovery process. The brain is very good at finding patterns and trends, and also, detecting abnormal behaviour in otherwise normal activities. Some software products are available to help users perform this task.

3.3.10.1 Miner3D

Miner3D (http://miner3d.com/) by DIMENSION 5, Ltd. is a data visualization software for multidimensional exploratory data analysis. It has a model builder that creates charts for the data loaded into the system, including support for creating several types of customizable 3D and 2D charts as shown in Figure 56.

Key features include:

- K-Means Clustering to cluster data sets visually in 3D.
- Data Interaction and Filtering to interactively reveal patterns and clusters in data and their layouts and decompositions in data models.
- Principle Component Analysis to rotate multi-dimensional data and thus reveal patterns.

Miner3D comes in three editions (basic, professional, and enterprise) and a developer edition that allows for web integration.

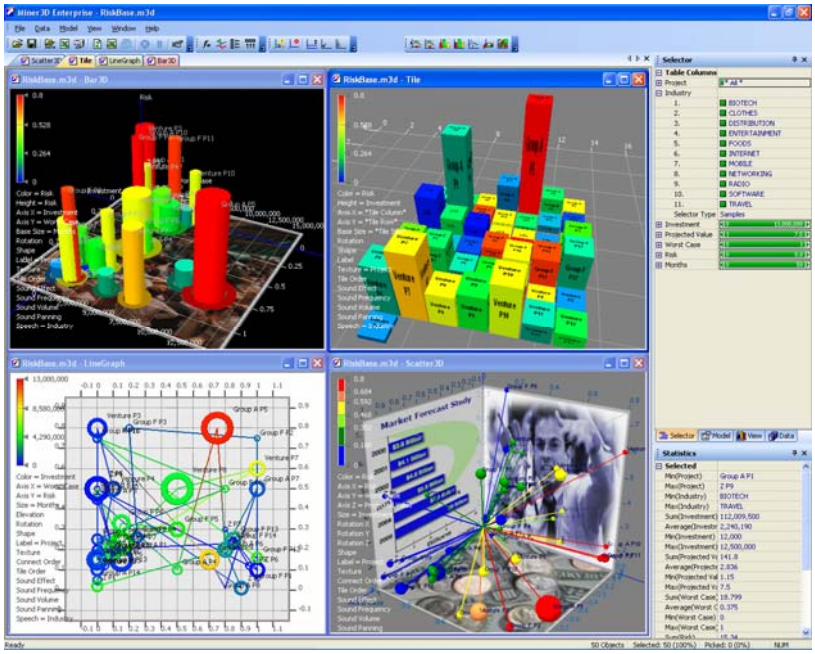


Figure 56. *Miner3D Supports Visual Data Mining*
Miner3D provides a variety of tools for re-projecting datasets into a form that reveals useful patterns.

3.3.10.2 Tableau

Tableau (http://www.tableausoftware.com/) is a visual analysis and reporting solution that allows people to explore and analyze databases and spreadsheets using drag and drop operations, as shown if Figure 57.

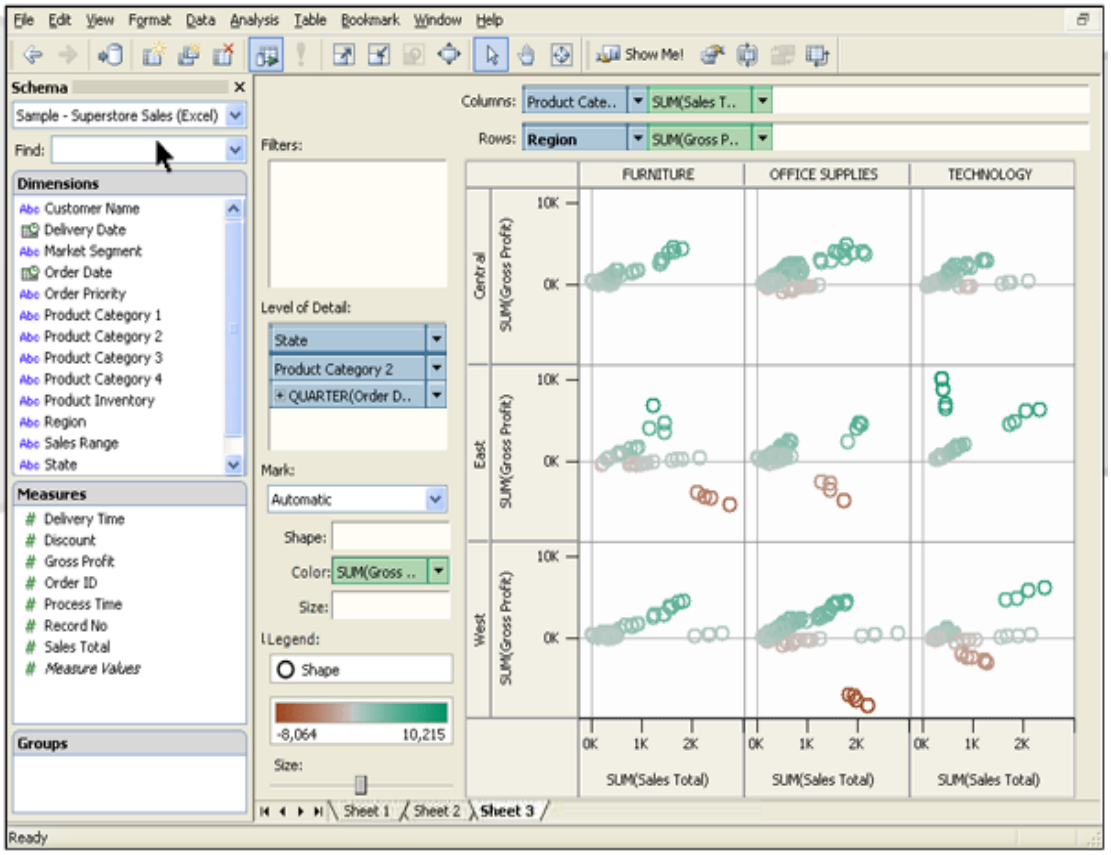


Figure 57. *Tableau Sample Showing Product Categories by Region*
Plots are created by dragging dimensions and measures from the Schema area, on the left, over to the plot area on the right.

3.3.10.3 I2 Analyst's Notebook

i2 Visual Notebook (http://www.i2inc.com/Products/) provides computer-aided drawing support for investigators to visually organize case information. The drawings can visually indicate connections between people, places, and events, as shown in Figure 58, and visualize sequences of events to compare between accounts and theories. It also provides some support for "drilling down" to get supporting information.

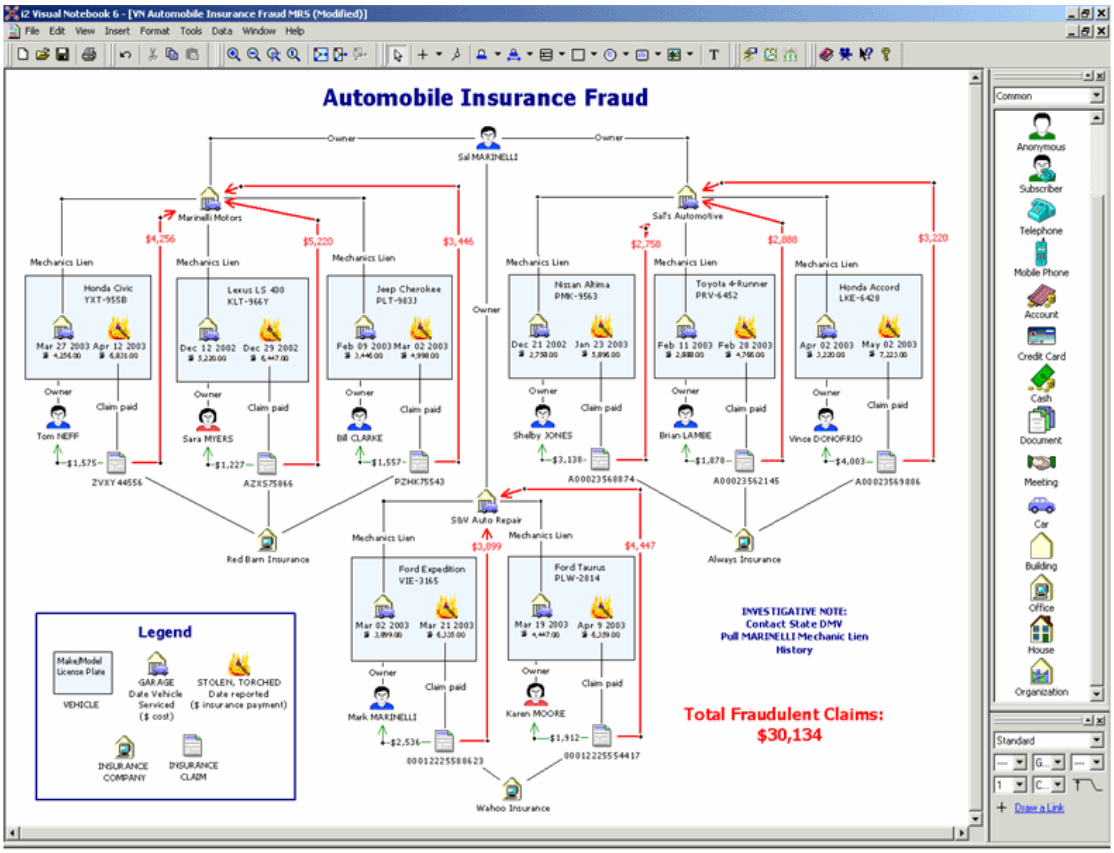


Figure 58. *Analyst's Notebook Example*

In this example, an analyst has used i2 to sketch an investigation into Automobile Insurance Fraud.

3.3.10.4 Purple Insight MineSet

Purple Insight's MineSet (http://www.purpleinsight.com/products/index.shtml) is an integrated suite of software tools for data mining and data visualization, including:

- Splat Visualizer (shown in Figure 59) and the Scatter Visualizer, which represent data in up to eight dimensions.
- Map Visualizer, which displays data with geographical relationships on a map.
- Animation techniques, which are used to reveal patterns over dimensions such as time.
- Tree Visualizer, which depicts data with hierarchical relationships in 3D.
- Statistics Visualizer, which presents a visual summary of basic statistical information with drill-through access to the original data.

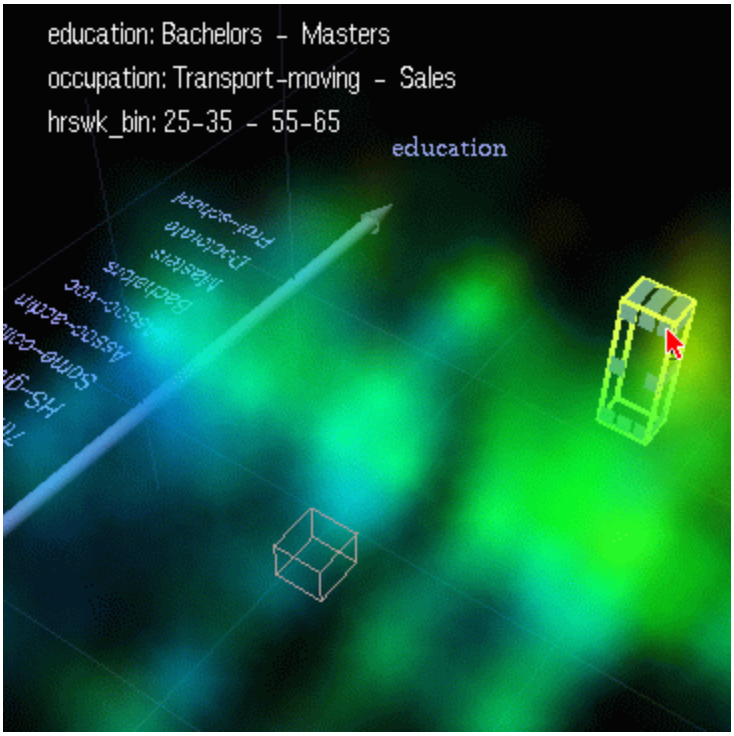


Figure 59. *Purple Insight's Splat Visualizer Looking at Education and Income*

The Purple Insight web page explains that this figure "shows how different education, type of job and number of hours worked fit together, with color representing salary -blue being lower and green being higher. We can see that a better education means more money, except that people who are non-bio-science academics work long hours and are paid poorly."

3.3.10.5 VxInsight

VxInsight (http://www.cs.sandia.gov/projects/VxInsight.html) is a tool for discovering relationships within large databases. It was created by Sandia National Laboratories with the Institute of Scientific Visualization and runs on SGI workstations. Figure 60 shows some example screens.

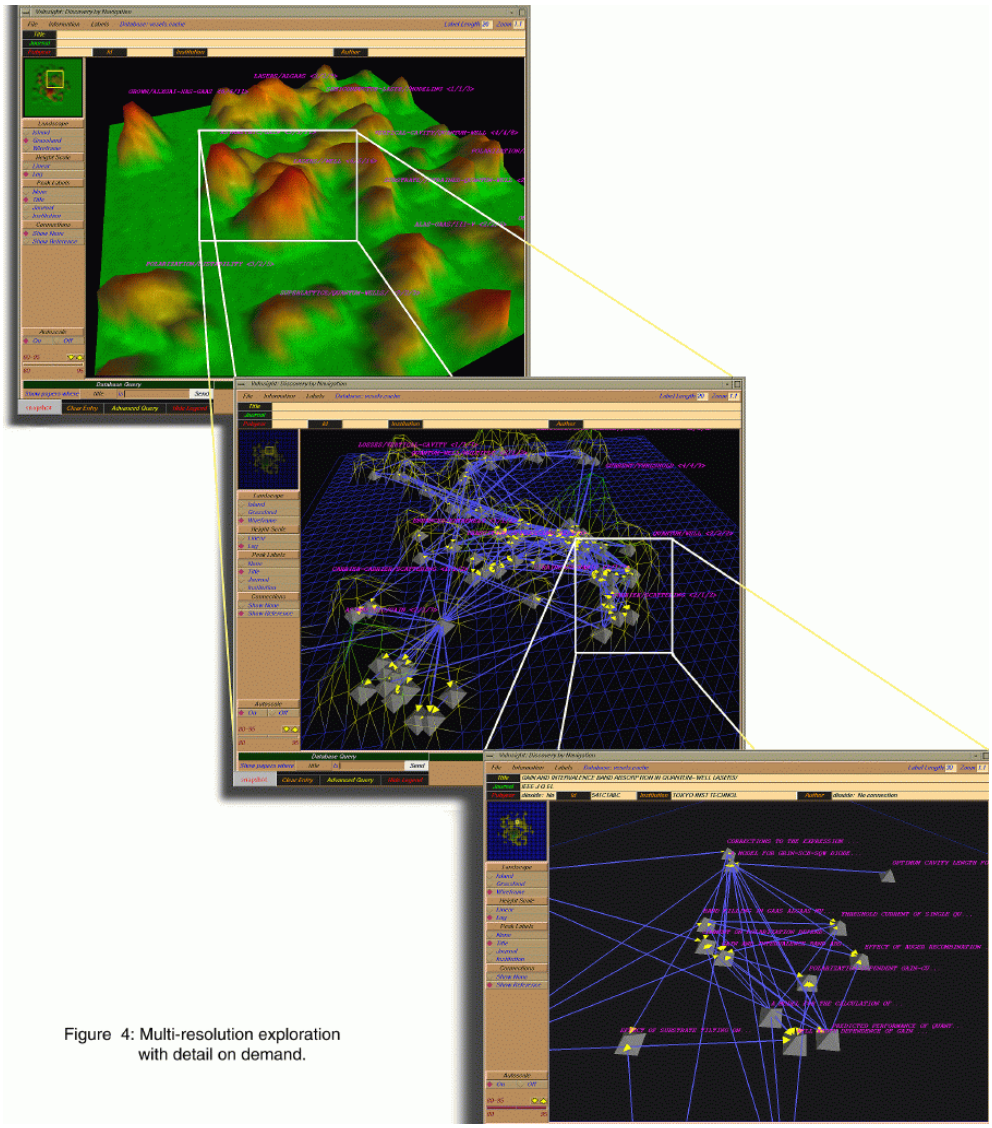


Figure 60. *Sandia Lab's VxInsight*
VxInsight provides views of very large data sets at varying scales, with accordingly greater or lesser levels of detail.

3.3.10.6 OmniViz

OmniViz (http://www.omniviz.com/applications/omni_viz.htm) is a text clustering and visualization application that allows mining of text documents. In addition to a typical ThemeMap display of the documents, OmniViz provides a feature called a "CoMet visualization" of the data which plots selected topics vs. documents.

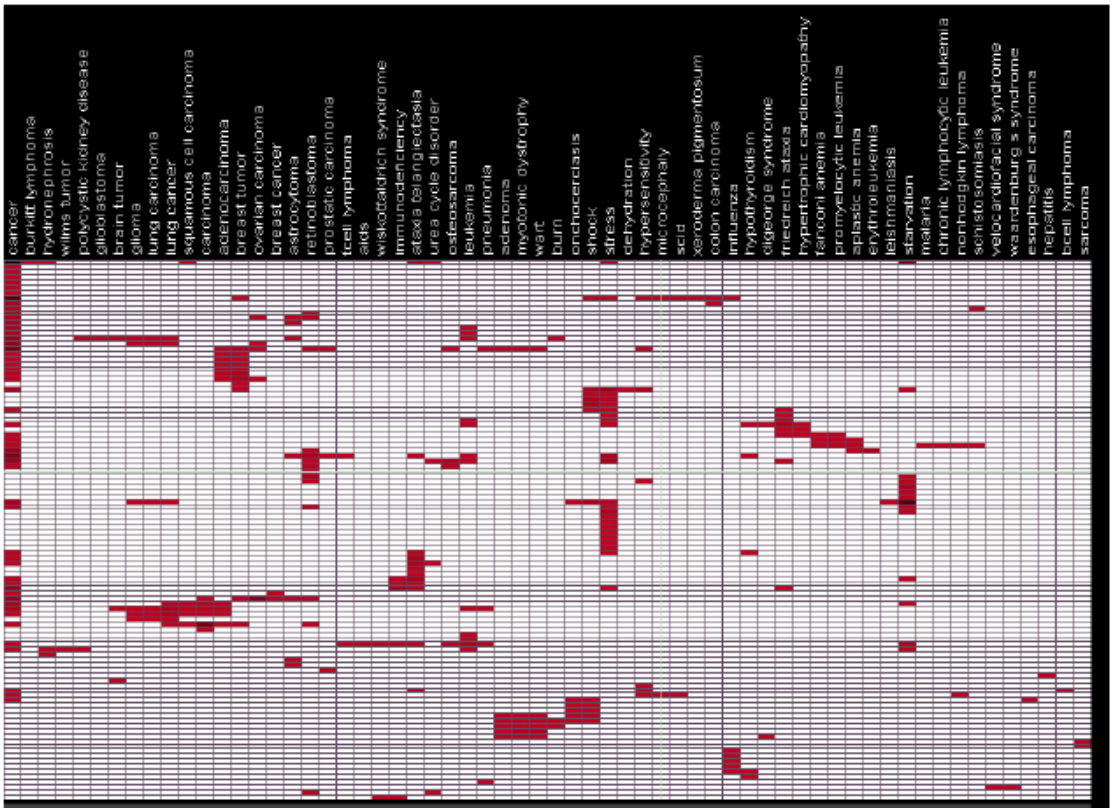


Figure 61. *OmniViz CoMet View of documents*

The CoMet tools visualizes co-occurrences of selected events, such as "which companies have collaborated together?" or "which compounds co-occur with which side-effects?" based on the textual content of the source data.

3.3.11 Other Potential Tools of Interest

This section addresses tools that were not included in the more in-depth investigations above. They were not covered for one of the following reasons:

- They were seen as interesting, but not directly relevant.
- Insufficient information was available on the products.
- It was not clear that the product could be applied to MISR, but could be relevant in similar situational awareness applications that might benefit the RMP.
- The product alluded to trends that could impact the RMP in the future, but are not relevant in the present or near term.

These products will not be reviewed in detail, but are included here for possible consideration or interest.

3.3.11.1 SAGE

Ref: http://www.cs.cmu.edu/Groups/sage/sage1.html

The System for Automated Graphics and Explanation (SAGE) is a research project of the Carnegie Mellon University School of Computer Science. This product seems to be at a prototype level, but does demonstrate some interesting information visualization concepts.

3.3.11.2 High Tower Network Visualization

Ref: http://www.high-tower.com/products.asp

This application is primarily a network security application, but would be of possible interest to operations centers that deal with MISR issues.

3.3.11.3 Advizor

Ref: http://www.visualinsights.com/solutions.htm

Advizor provides a number of dataset discovery tools that deal with a number of topics. It seems to deal with conventional information visualization concepts, and targets them at enterprise customers.

3.3.11.4 ClearForest

Ref: http://www.clearforest.com/Products/Platform.asp

We were unable to find much information on this product. It is targeted at business analytics and data navigation. It seems to focus on targeting and navigating unstructured data sources.

3.3.11.5 Vista

Ref: http://forrest.psych.unc.edu/research/vista-frames/welcome.html

Vista appears to be a statistical analysis toolkit that provides a number of tools for displaying results. The display tools are, for the most part, conventional, but it does have some interesting display techniques for understanding data structure and data analysis workflow.

3.3.11.6 SAS Enterprise Miner

Ref: http://www.sas.com/technologies/analytics/datamining/miner/

SAS is well known for their statistical heritage. They also have tools that support data extraction and data mining. While some aspects of this capability involve visualization, much of the GUI capability is focused on allowing the user to enter the extraction criteria/goals to generate results.

3.3.11.7 DB2 Intelligent Mining

Ref: http://www-306.ibm.com/software/data/iminer/

As with the SAS Enterprise Miner, IBM has developed a data discovery framework that has some information visualization components included. There is a Java visualization capability included in this framework to support information visualization.

3.3.11.8 NetMap Analytics

Ref: http://www.altaanalytics.com/

This software is targeted at the insurance industry, but it introduces concepts and techniques that are interesting. The insurance industry arguably deals with some of the largest and most complex data sets. Furthermore, accurate interpretation of this information is critical to their success. NetMap Analytics has developed software that focuses on the analysis and discovery of trends in data to support insurance providers.

3.3.11.9 Aperture

Ref: http://www.aperture.com/

Aperture software is focused on IT infrastructure management and visualization.

3.3.11.10 Jellyfish

Ref: http://www.carohorn.de/jellyfish/index.htm

This is largely conceptual, but it does explore a different medium for clustering and managing hierarchical information.

3.3.11.11 LifeLine

Ref: http://www.geog.port.ac.uk/lifeline/

This academic project is exploring different techniques for presenting timeline data. No new information visualization techniques are shown, but it does show novel ways of using standard information visualization techniques.

3.3.11.12 N-dimensional Numerical Tools

There are a large number of mathematical packages that provide inherent numerical visualization capabilities:

Tecplot: http://www.genias-graphics.de/cms/tecplot.html

Ensight: http://www.genias-graphics.de/cms/ensight.html

Matlab: http://www.mathworks.com

Mathematica: http://www.wolfram.com/

PVWave: http://www.vni.com

Visual Numerics: http://www.vni.com/index.html

IDL: http://www.rsinc.com/

CViz: IBM has prototyped technologies for visualization and management of massively large data sets. http://www.alphaworks.ibm.com/tech/cviz

Xgobi: a research project that explores the issues associated with visualization of datasets with many dimensions. http://public.research.att.com/~stat/xgobi/

Ggobi: appears to be a follow-on to Xgobi. http://www.ggobi.org/

Databionic ESOM: the "SourceForge" project "Databionic Emergent Self-Organizing Maps" is focused on management and presentation of complex, linked information. http://databionic-esom.sourceforge.net/

4 Visualization Research Requirements for MISR

The following subsections speculate about whether improved visualization algorithms can aid maritime ISR activities, and propose some topics for further research and development. The discussion focuses on the following three maritime ISR questions:

- Are there any ships that we don't know about? (Section 4.1)
- Are any of the known ships behaving strangely? (Section 4.2)
- Do the cargo or crew of any ship raise security concerns? (Section 4.3)

4.1 Surveillance Coverage and Trajectory Space

In order for operators to be thoroughly aware of surveillance coverage, they need to have a good visual sense of where and when the sensors have looked, and where they have not looked. Visualization research can contribute to this by providing strategies to:

- visualize sensor swaths including:
  - What region of the ROI was observed by the sensor?
  - How did the probability of detection vary over that swath (taking into account for example visibility, weather conditions, ship size, and ship type)?
  - When was the swath collected (relative to "now" or relative to a variable time-slider, for example)?
- visualize gaps in the coverage, including:
  - highlighting locations that have not been viewed;
  - relating the gaps to possible ship motions (e.g. could a ship travelling at 22 knots have been missed by all sensor swaths?)

The paper that we found addressed these issues best was by Hew (Hew 2003b) from DSTO Australia. Figure 62 shows, for example, how Hew displayed coverage swaths and their staleness. Hew also started to search for ways to relate coverage gaps to possible ship motions using a "trajectory space," as shown in Figure 63, but his publications do not make it clear how successful this was.

As part of the Polar Epsilon research, MDA developed a tool for visualizing potential coverage gaps for ships traveling along a known shipping lane (Davenport 2004), as shown in Figure 64. One criticism of this graphic is that it is not self-evident how to interpret it.

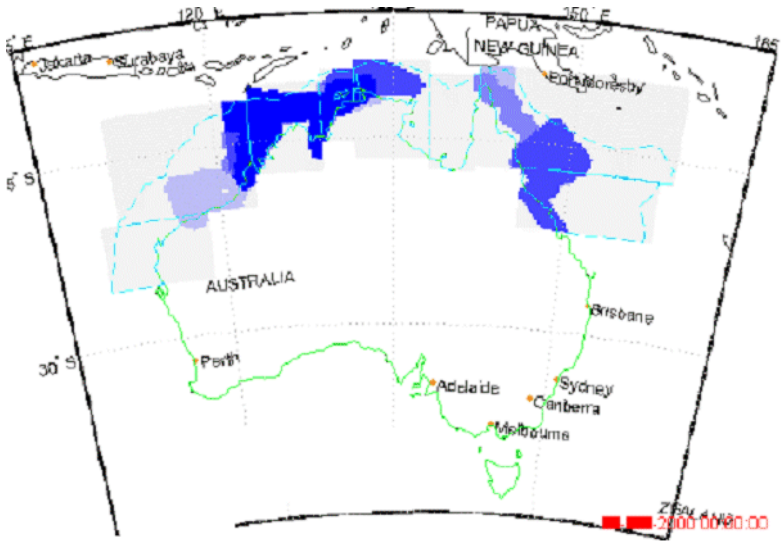


Figure 62. *Hew's Visualization of Coverage Swaths*
In this example, areas covered by surveillance are painted dark blue. The paint fades to lighter blues as the coverage becomes stale.

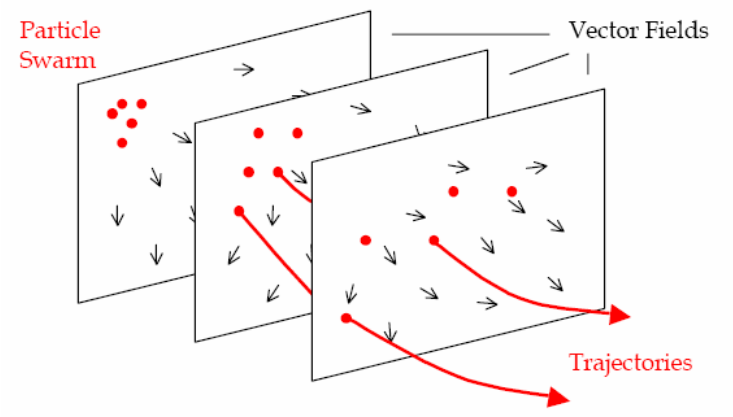


Figure 63. *Hew's Trajectory Space*
Hew tried to relate gaps in coverage to possible ship trajectories using a "trajectory space" in which swarms of ships with randomly-selected locations, speeds, and headings were superimposed on recent coverage swaths.

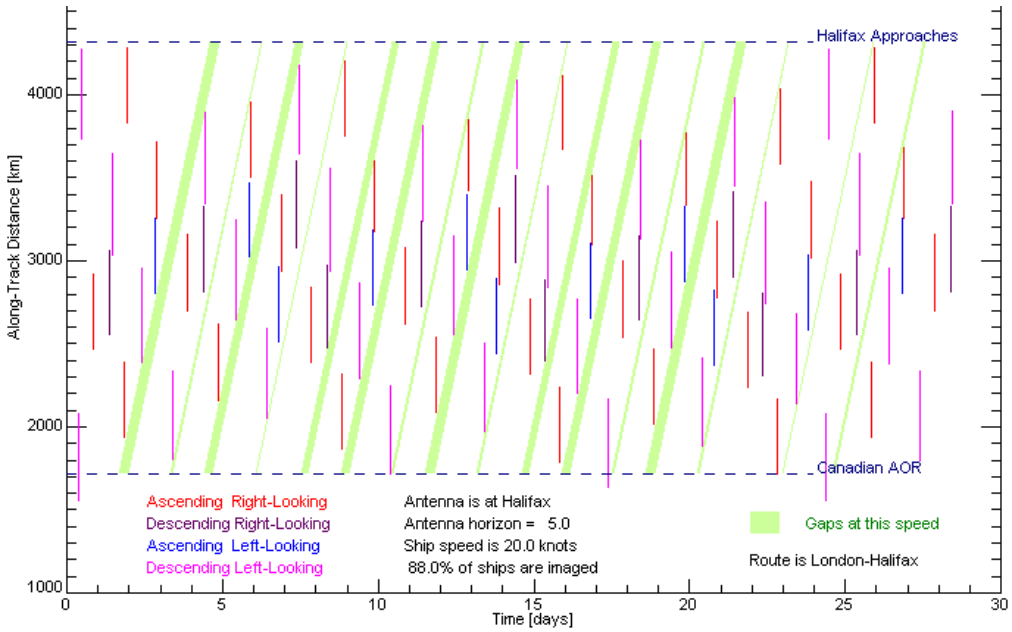


Figure 64. *Visualizing Coverage Gaps Along a Shipping Lane*
This plot illustrates how well Polar Epsilon's future RADARSAT 2 surveillance will be able to patrol the great-circle shipping route from London to Halifax. Radar swaths are plotted as vertical lines, arranged along a horizontal time axis marking the time of the over-flight and with length equal to the extent of each swath. Ships travel up and to the right, with faster speeds corresponding to steeper plots. The slanted green lines show coverage gaps, in this case for ships travelling at 20 knots. (Source (Davenport 2004) Figure 7-16)

4.2 Visualizing Ship Behaviour

A second challenge for MISR visualization is the effective portrayal of both position and movement of the ships that are being tracked. In the current GCCS, for example, it can be quite time-consuming to determine whether two ships, whose tracks cross on the screen, came anywhere near each other.

It is tempting to view this as a three-dimensional visualization problem: the ships move on a two-dimensional surface, and time is the third dimension. That is the approach taken by GeoTime, as introduced in Section 3.3.9.2 and as shown in Figure 65. Not surprisingly, such a projection is vulnerable to excessive clutter, as shown on the right side of the Figure, which can obscure rather than reveal patterns. Clutter can be suppressed using well-tested strategies, but it illustrates how much more difficult it will be for operators to work in this domain.

An alternative solution may be to offer co-moving spatial coordinate systems, but we have not seen any projects that attempt this. The potential advantage is that it would allow the graphics to remain two-dimensional, while still analysing motion-related relationships.

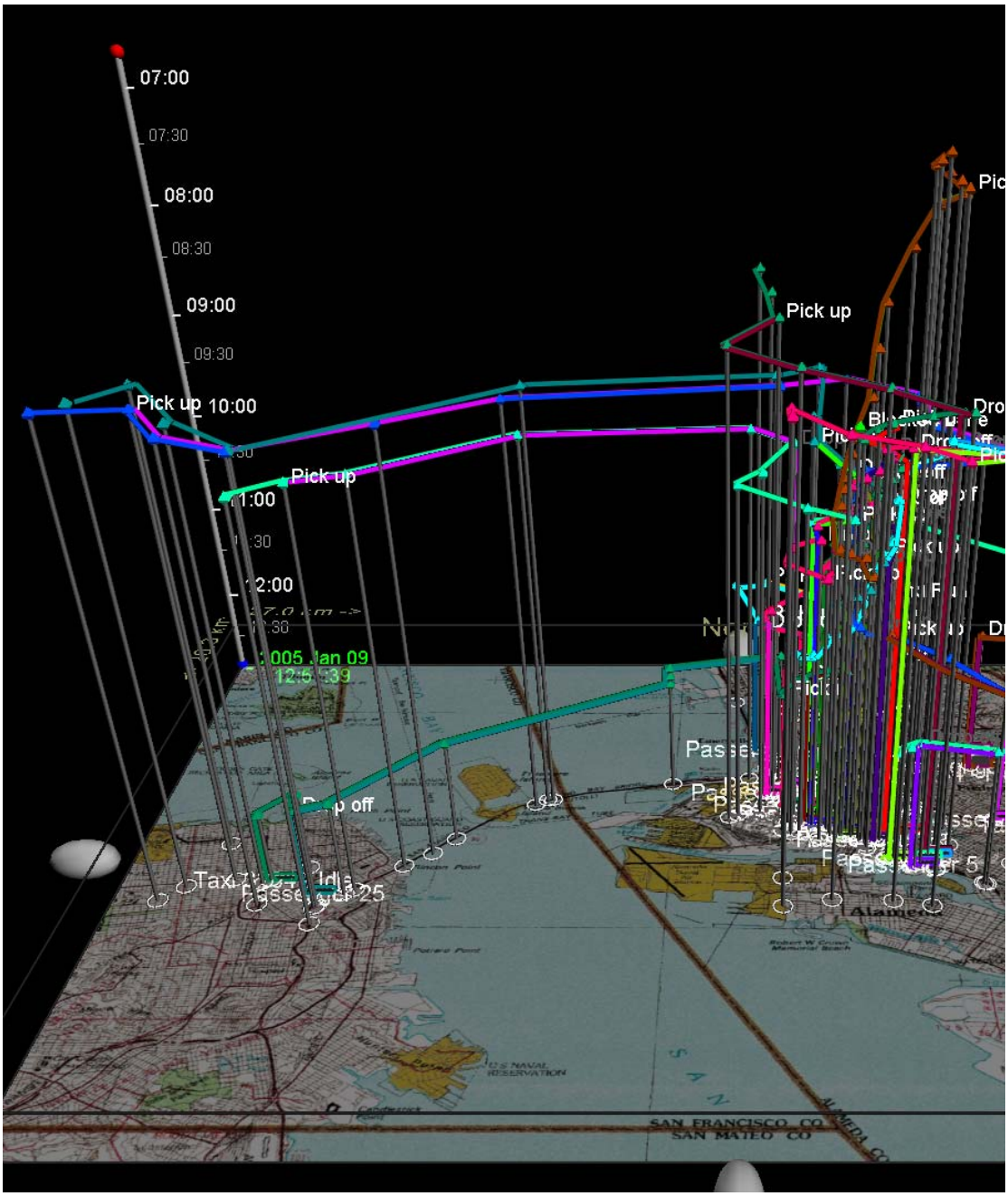


Figure 65. *GeoTime Visualization of Time as the Z-Dimension*
GeoTime uses the vertical third dimension to represent time – here indexed by the time axis projecting downward from the red ball in the upper left corner. Exact spatial locations are referenced to the underlying map using vertical bars, and exact time values are accessible by pointing at events. (source http://java.sun.com/products/jfc/tsc/sightings/S23/Oculus/7.png)

4.3 Detecting Anomalous Behaviour

An important goal of Maritime ISR visualization is to push routine ship behaviour into the background, and highlight the behaviour that demands special attention. This can be done, for example, in the following ways:

a. identify when a target approaches or enters a designated "alert" area;

b. identify when a target behaves very differently from usual;

The first of these (a) is probably just a simple matter of drawing the boundaries of the alert area on the AOR – no special visualization is required. The second requires that MISR extract patterns of "usual" behaviour from the track databases, and provide visualization support to compare them to current tracks. We did not find any visualizations that did this specifically, but Figure 66 shows one attempt at extracting the patterns of "usual" behaviour. A more sophisticated approach would examine the time-dependence of ship call-in locations.

Figure 66. *Data Mining to Determine "Usual" Ship Motion*
A simple plot of locations of all voluntary weather reporting ships, over a one-month period, gives useful information about shipping lanes and shipping density. (source www.itu.int/md/R03-WP8B-C-0242/en)

4.4 Attributes of Maritime Targets

A third visualization challenge for MISR is to create awareness of the attributes of vessels, such as:

- ship owner
- class of cargo
- pedigree of the cargo (where it came from, how well checked it is)
- officers and crew

This moves us into the realm of visualizing abstract data spaces that are only loosely linked to geospatial coordinates. Although challenging, this is an area of active research on many fronts, as described in Sections 2.3 and 3.3.

Starlight is illustrative of the state of the art in general-purpose attribute visualization tools. Figure 67 for example shows attribute data layers from a fictional disease outbreak, linked to each other and linked to a geospatial frame of reference. However it is not clear from this example what the added value of the visualization is, nor is it clear whether Starlight has generated this view automatically, or whether it was hand-crafted by an operator. In other words, is Starlight useful because it reveals patterns to operators, or because it helps operators "paint pictures" of the patterns that they have discovered.

Even if the patterns are not being automatically revealed, the breakthroughs that we see in Starlight are still important, because only as we gain experience with the hand-crafted visualizations can we begin to specify what functionality we need from automated visualizations.

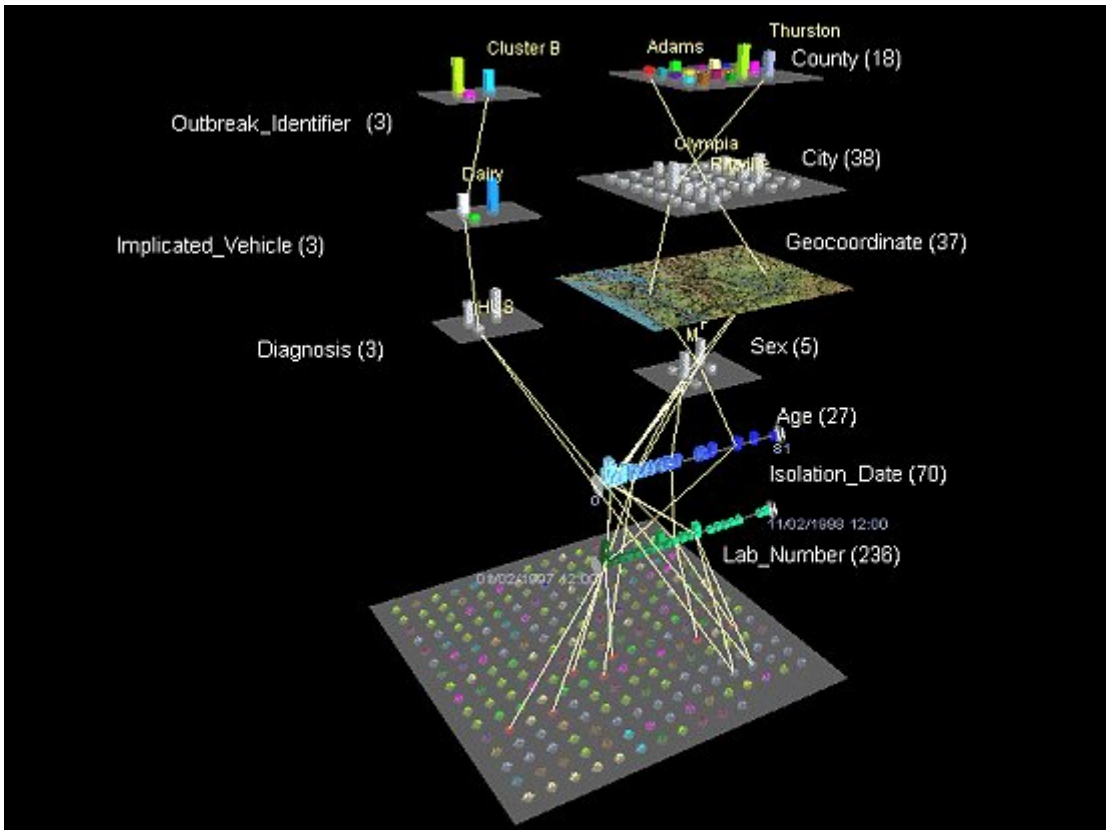


Figure 67. *Starlight Visualization of Attribute Data*
In this example, Starlight paints a picture of a disease outbreak, linking attribute data such as disease-carrying vehicle (probably a dairy product) and the ages of the victims to geospatial data about where the victims live. (source: http://starlight.pnl.gov/vizLocalArrays.stm)

5 Conclusions and Future Work

Our study of visualization algorithms and products has revealed a rich research community and a wealth of visualization ideas. With respect to their relevance to Maritime ISR, these fall very roughly into the following categories:

- A number of papers (as listed in Sections 2.5.5 and 2.5.2 for example) contribute to establishing an ambitious vision for what can be achieved with MISR visualizations, and corresponding MISR requirements, but offer no specific design solutions;

- The large group of texts and papers on Human Factors (see Section 2.4.8) offer no specific solutions to MISR requirements, but provide quantitative theories and observations with which to evaluate new ideas;

- A few of these ideas, such as the NewsMap (Section 3.3.5.4) and the Pliable Display Technology (Section 3.3.8.10) are mature capabilities that could add value to current MISR systems, given appropriate adjustments to CONOPS;

- Many of the specific solutions listed in Sections 2.4 and 2.5.6 are probably not directly applicable to MISR, but provide a good "catalog of what is possible" to help guide the MISR developments;

- Some of the specific visualization examples are relevant to MISR and may one day be very useful, but suffer from a lack of automation. Such examples stand more as "works of art" than "operational prototypes" but they nonetheless contribute significant value to the extent that they open up new possibilities for the operational engineering that must follow.

Most of the specific MISR visualization problems listed in Section 4 thus remain unsolved. We recommend that research such as the following should be undertaken, and that in all cases it should maintain a long-term vision for automated rather than hand-crafted visualizations:

1. **Visualizing Coverage and Ignorance:** Starting with Hew's concepts (Section 4.1) develop new methods for portraying sensor coverage, including coverage that degrades in space and time (i.e. has fuzzy edges) rather extending over a sharply-defined swath. Investigate ways to visualize gaps in coverage that result from time-displacements as well as spatial displacements of sensor swaths;

2. **Visualizing Ship Tracks in Time and Space:** Investigate whether the GeoTime portrayal of tracks and events in space and time (Section 4.2) can be used effectively for the large spatial areas and surveillance durations of MISR. Search for new simpler projections that convey the required time information, such as co-moving frames of reference;

3. **Visualizing "Normal" Behaviour of Ships:** Using easily-acquired data such as that shown in Figure 66, investigate how temporal and spatial patterns of ship behaviour can be visualized to provide operators with a better understanding of what is "normal". Demonstrate how new tracks can be co-displayed with historical patterns to identify anomalous behaviour.

4. **Visualizing Attribute Data of Interest to MISR:** Identify and prioritize attribute data (e.g. cargo, crew, ownership history, etc.) that may be of interest for MISR. Using one or more of the toolkits listed in Section 3.3, demonstrate how such data could be co-visualized with the Maritime Picture. Investigate the value of different visualization strategies in highlighting the patterns that are of greatest interest for Canadian MISR operations.

List of symbols/abbreviations/acronyms/initialisms

AFRL	Air Force Research Laboratory
AOR	Area of Responsibility
APIs	Application Programming Interface
ARMADA	Applied Research for Maritime Domain Awareness
AVS	Advanced Visualization System
BSD	Version of UNIX from University of California at Berkeley
CEV	Center for Environmental Visualization
CHI	Computer Human Interaction
COMSEC	Communication Security
CONOPS	Concept of Operations
CPU	Central Processing Unit
DND	Department of National Defence
GIS	Geographic Information System
IBM	International Business Machines
IGARSS	International Geoscience and Remote Sensing Symposium
ISBN	International Standard Book Number
ISR	Intelligence, Surveillance, and Reconnaissance
IT	Information Technology
JDBC	Java Database Connectivity
JUNG	Java Universal Network/Graph Framework
LCD	Liquid Crystal Display

METOC	Meteorology and Oceanography
MISR	Maritime Intelligence, Surveillance, and Reconnaissance
MOEs	Measures of Effectiveness
OLAP	On-Line Analytical Processing
OSX	Mac Operating Systems “X”
PC	Personal Computer
PDT	Pliable Display Technology
PWGSC	Public Works and Government Services Canada
QT	C++ Drawing Library from TrollTech
RMP	Recognized Maritime Picture
SAGE	System for Automated Graphics and Explanation
SDK	Software Development Kit
SDOF	Semantic Depth of Field
SGI	Silicon Graphics, Incorporated
SOCs	Surveillance Operations Centers
SOW	Statement of Work
VIS	Visualization Conference
XGA	eXtended Graphics Array
XML	eXtensible Markup Language
ZUIs	zoomable user interfaces

Annotated Bibliography

(Aasgaard 2002) R. Aasgaard, "Do we have to see everything - all the time?" *Proc. Massive Military Data Fusion and Visualisation: Users Talk with Developers,* Halden, Norway, 2002.

http://www.vistg.net/Halden/presentations/Session%203/Aasgaard.ppt

Keywords: Overload

Discussion of the importance of having the right amount of detail in a model. Generally applicable, but most examples are from land. No citations.

(Acevedo 2006a) D. Acevedo, "Art, Perception, and Visualization. IEEE Vis and InfoVis." Visualization Research Lab: Resources, 2006a.

http://vis.cs.brown.edu/resources/lists/art.html,

Keywords: Review Article

This is Acevedo's list of key papers from IEEE Vis and Info Vis publications, but it does not live up to expectations.

(Acevedo 2006b) D. Acevedo, "InfoVis and Homeland Security List". Visualization Research Lab: Resources, 2006b.

http://vis.cs.brown.edu/resources/lists/hls.html,

Keywords: Review Article

This is a list of papers that are, in Acevedo's opinion, key papers on Homeland Security Visualization. That sounds really great, but in reality the list is thin and not very helpful.

(ACM 1981-2006) ACM. Conference on Human Factors in Computing Systems (SIG-CHI), Portland, Oregon, Association for Computing Machinery, 1981-2006.

http://portal.acm.org/toc.cfm?id=SERIES260&coll=ACM&dl=ACM&type=series&idx=1056808&part=Proceedings&WantType=Proceedings&title=Conference%20on%20Human%20Factors%20in%20Computing%20Systems&CFID=52846111&CFTOKEN=89657493,

Keywords: Conference Stream Quality = 2 2 1 1 2

The ACM SIG-CHI (Special Interest Group on Computer-Human Interaction) conference stream includes many papers that are relevant to visualization, but is not primarily concerned with visualization.

(Alberts et al. 2002) B. Alberts and W.A. Wolf, Making the Nation Safer: The Role of Science and Technology in Countering Terrorism, National Academy of Sciences, 2002.

Keywords: Requirements; Defence

Mostly about Information Technology rather than visualization technology. Relevant to MISR because of the association with Homeland Defense issues in the US.

(Alward 2002) R.G. Alward, "Keynote Address II: A Military C2 Professional's Thoughts on Visualization", *Proc. Massive Military Data Fusion and Visualisation: Users Talk with Developers,* Halden, Norway, 2002.

http://vistg.net/Halden/presentations/Session%201/Need%20for%20VisualizationV2.ppt,

Keywords: Requirements; Defence

These are PowerPoint slides from a talk given from Alward about the need for visualization, though mostly in the abstract information sphere rather than concrete operational requirements. Frankly a lot of the things he says are generalizations, perhaps because these slides were intended to be presented as part of a verbal presentation.

(Amar et al. 2005) R. Amar and J.T. Stasko, "Knowledge Precepts for Design and Evaluation of Information Visualizations" IEEE Transactions on Visualization and Computer Graphics **11**(4), 2005.

http://www-static.cc.gatech.edu/~john.stasko/papers/tvcg05.pdf

Keywords: Requirements ; Uncertainty

This paper is about the high-level planning for when and why and what to visualize. It gives perspective on the analysis process that must precede implementation. The authors are not senior or widely known in the field, so it is somewhat surprising that they have tackled this fundamental issue, but they write clearly.

(Andrienko et al. 2003) N. Andrienko and G. Andrienko, "Exploratory Analysis of Spatial Data and Decision Making Using Interactive Maps and Linked Dynamic Displays", *Proc. EMCL/PKDD,* Cavtat/Dubrovnik Croatia, 2003.

http://www.commongis.com/tutorial/tutorial-PKDD-2003.html,

Keywords: Time and Space ; Software Resource

This is an outline of a tutorial given by these authors. It focuses on GIS-style linkages (and in fact the authors are from a GIS background) between geography and non-geographic information, but visualizes those linkages using state of the art visualization techniques.

(Andrienko et al. 2006) N. Andrienko and G. Andrienko, *Curriculum Vitae*, Fraunhofer AIS – Institute for Autonomous Intelligent Systems online C.V. Accessed 2006.

http://www.ais.fraunhofer.de/and/,

Keywords: Research Leader

This is a single entry for two experts, because in all the literature they never seem to act alone. Although the Andrienkos have a background in GIS and mapping, and maintain their links with that community, they are extraordinarily active in the visualization community, particularly in Europe. They play key roles in numerous international R&D projects, including EU-funded projects, and are active members of several commissions of the International Cartographic Association, including the Commission on Visualization and Virtual Reality.

(Andrienko et al. 2005) N. Andrienko and A. G., Exploratory Analysis of Spatial and Temporal Data - A Systematic Approach, Springer, Springer, 2005.

Keywords: Time and Space ; Visual Analytics ; Textbook

We were not able to get a copy of this book in time to review it. The background of the authors includes both visualization and mapping, so we expect that this book is rich in visualization material. It will bring a European flavour, which may act as a useful balance in this North-American dominated field.

(Ankerst et al. 1998) M. Ankerst, S. Berchtold and D.A. Keim, "Similarity Clustering of Dimensions for an Enhanced Visualization of Multidimensional Data ", *Proc. IEEE Symposium on Information Visualization* Washington, D.C., p. 52-60, 1998.

http://citeseer.ist.psu.edu/context/1216800/0,

Keywords: Software Resource Quality = 1 ? 1 ? 2

This describes a mathematical and analytical approach to one of visualization's hard problems: selecting which dimensions of the data to display in order to reduce redundancy and reveal novelty.

(Arsenault et al. 2006) R. Arsenault, M. Plumlee, A. Foulks, D. House, L. Mayer, S. Smith and C. Ware, "GeoZui3D: A System for Rapid Interaction with 3D Data Spaces", 2006.

http://www.ccom.unh.edu/vislab/GeoZui3D.html,

Keywords: Software Resource

This is the home page for a software tool for interactively visualizing 3D spaces, and hence might be valuable as a generic resource.

(Balzer et al. 2005) M. Balzer and O. Deussen, "Voronoi Treemaps ", *Proc. IEEE Symposium on Information Visualization* p. 7, 2005.

http://doi.ieeecomputersociety.org/10.1109/INFOVIS.2005.40,

Keywords: Software Resource ; Tabular data

This is a specific application of treemaps.

(Barlow et al. 2001) T. Barlow and P. Neville, "Visualization for Decision Tree Analysis in Data Mining ", *Proc. IEEE Symposium on Information Visualization 2001*, p. 149-152, 2001.

http://csdl2.computer.org/persagen/DLAbsToc.jsp?resourcePath=/dl/proceedings/&toc=comp/proceedings/infovis/2001/1342/00/1342toc.xml&DOI=10.1109/INFVIS.2001.963292,

Keywords: Software Resource

A specific software tool for decision trees.

(Bartram et al. 2002) L. Bartram and C. Ware, "Filtering and Brushing with Motion" Information Visualization **1**(1): 66-79, 2002.

http://www.palgrave-journals.com/cgi-taf/DynaPage.taf?file=/ivs/journal/v1/n1/abs/9500005a.html&dynoptions=doi1143744843,

Reviews the use of motion as an efficient way to visualize groups of objects. Three types of motions were compared: linear, circular and expansion/contraction. Conclusions: 1) motion can effectively group objects that are otherwise dissimilar 2) type of motion works better that direction of motion (except 90 degree direction change) 3) circular motion demands the most attention.

(Basu et al. 2002) A. Basu and S. Malhotra, "Error detection of bathymetry data by visualization using GIS" ICES Journal of Marine Science **59**(1): 226-229, 2002.

Keywords: METOC ; Uncertainty

(Baudisch 2006) P. Baudisch, "Interacting with Wall-Size Screens", *Proc. Information Visualization and Interaction Techniques for Collaboration across Multiple Displays* Montreal, 2006.

http://nvac.pnl.gov/ivitcmd_chi06/papers/Patrick.pdf

Keywords: Display Hardware ; Human Factors

This is a summary of research into how user interactions need to change when working on very large screens.

(Bauer et al. 1999) M. Bauer, G. Kortuem and Z. Segall, "Where Are You Pointing At: A Study of Remote Collaboration in a Wearable Videoconference System", *Proc. Third International Symposium on Wearable Computers*, p. 151-158, 1999.

Keywords: Collaboration

Looks at issues of collaborative visualization when using wearable computers.

(Bederson et al. 2004) B. Bederson, A. Clamage, M. Czerwinski and G. Robertson, "Ordered and Quantum Treemaps: Making Effective Use of 2D Space to Display Hierarchies" ACM Transactions on Graphics **21**(4): 833-854, 2004.

http://www.cs.umd.edu/class/spring2006/cmsc838s/StudentPresentations/0221_TreeMap.ppt

(Bederson et al. 2003) B. Bederson and B. Schneiderman, The Craft of Information Visualization: Readings and Reflections, Morgan Kaufmann, 2003.

http://www.amazon.com/gp/product/1558609156/102-8880711-9707369?v=glance&n=283155,

Keywords: Textbook Quality = 2 2 0 1 2

This is a collection of papers rather than a true textbook, and hence somewhat lacks continuity and comprehensiveness. None of the papers have direct relevance to MISR.

(Beermann et al. 2005) D. Beermann, T. Munzner and G. Humphreys, "Scalable, Robust Visualization of Large Trees", *Proc. Euro Vis 2005*, 2005.

http://www.cs.virginia.edu/~gfx/pubs/TJC/,

http://www.cs.virginia.edu/~gfx/pubs/TJC/tjc.pdf

Keywords: Software Resource

Specific solution to the problem of building large treemaps.

(Bergman et al. 1995) L.D. Bergman, B.E. Rogowitz and L.A. Treinish, "A Rule-Based Tool for Assisting Colormap Selection", *Proc. Visualization* p. 118-125, 1995.

http://www.research.ibm.com/dx/proceedings/pravda/index.htm,

Keywords: Software Resource ; Human Factors

Rule-based system to help users select display characteristics.

(Bertin 1981) J. Bertin, Graphics and Graphic Information Processing, Walter de Gruyter 1981.

http://www.amazon.com/gp/product/3110088681/qid=1149181075/sr=1-6/ref=sr_1_6/102-8880711-9707369?s=books&v=glance&n=283155,

Keywords: Graphics

Out of print.

(Bertin 1983) J. Bertin, Semiology of Graphics University of Wisconsin Press 1983.

Keywords: Graphics Quality = 2 ? 2 ? 2

Out-of-print book that is widely admired and often cited. Colin Ware (Ware 2004) calls it Bertin's "great masterwork."

(Bobrow et al. 2005) R.J. Bobrow and A. Helsinger, "Kinetic Visualizations: A New Class of Tools for Intelligence Analysis", *Proc. 2005 International Conference on Intelligence Analysis,* McLean, VA 2005.

https://analysis.mitre.org/proceedings/Final_Papers_Files/231_Camera_Ready_Paper.pdf

Keywords: Time and Space

A very interesting article that looks at how to visualize motion, visualize motion statistics, and how to use motion cues to visualize other information. As MISR deals with moving objects, this seems very relevant.

(Börner 2005) K. Börner, "InfoVis Cyberinfrastructure ". Information Visualization Cyberinfrastructure, 2005.

http://iv.slis.indiana.edu/,

Keywords: Software Resource ; Tabular data ; Collaboration

A collection of software tools developed by academics and in the public domain. Primarily for visualizing massive amounts of information in terms of attributes, links between nodes, and tree structures. Includes some support for XML.

(Brandes et al. 2005) U. Brandes, D. Fleischer and J. Lerner, "Highlighting Conflict Dynamics in Event Data", *Proc. IEEE Symposium on Information Visualization* p. 14, 2005.

http://www.inf.uni-konstanz.de/algo/publications/bfl-hcded-05.pdf

Keywords: Software Resource

Develops a "Conflict Space" that helps visualize patterns of conflicts (wars, terrorist attacks, etc.). This may be very helpfulin analysing maritime threats.

(Brown et al. 1995) J.R. Brown, R. Earnshaw, M. Jern and J. Vince, Visualization: Using Computer Graphics to Explore Data and Present Information, New York, John Wiley and Sons, 1995.

Keywords: Graphics

Seems to be aimed at business visualizations rather than state of the art research.

(Buja et al. 1991) A. Buja, J.A. McDonald, J. Michalak and W. Stuetzle, "Interactive data visualization using focusing and linking", *Proc. 2nd conference on Visualization '91,* San Diego, California, p. 156 - 163 1991.

http://portal.acm.org/citation.cfm?id=949633,

Keywords: Software Resource

Specific solution for highly-dimensional data linking. Much has been done since this was written.

(Burrough et al. 1995) P.A. Burrough and A.U. Frank, "Concepts and Paradigms in Spatial Information: Are Current Geographical Information Systems Truly Generic?" International Journal of Geographical Information Systems **9**(2): 101-116, 1995.

http://www.dpi.inpe.br/gilberto/references/burr_af_are_gis_generic.pdf

Keywords: Requirements

At the core of this article is the statement that "spatial data analysis tools need to be chosen and developed to match the way users perceive their domains: these tools should not impose alien thought modes on users." That is the main (perhaps the only) relevance of this article to MISR visualization.

(Card et al. 1999) S.K. Card, J.D. MacKinlay and B. Shneiderman, Readings in Information Visualization: Using Vision to Think, Morgan Kauffman, 1999.

http://www.amazon.com/gp/product/1558605339/102-8880711-9707369?v=glance&n=283155,

Keywords: Textbook ; Visual Analytics Quality = 2 2 1 1 2

Chen refers to this as a "bible of the field" and it is useful for browsing through the various visualization fields (e.g. N-dimensional worlds, treemaps, networks, fisheye lenses, starfields, etc.) Because it is a compilation of articles from various authors, it lacks the continuity of a textbook such as (Chen 2003) but some of the articles (e.g. "A Review and Taxonomy of Distortion-Oriented Presentation Techniques" by Leung and Apperley) are good review articles in and of themselves. The editors' bias is toward interactive visualizations which is now referred to as "Visual Analytics."

(Card et al. 1991) S.K. Card, G.G. Robertson and J.D. Mackinlay, "The information visualizer, an information workspace ", *Proc. SIGCHI conference on Human factors in computing systems,* New Orleans, 1991.

Keywords: Software Resource

(Chen 2000) C. Chen, "Empirical studies of information visualization: a meta-analysis" Int. J. Human-Computer Studies **53**: 851-866, 2000.

Keywords: Review Article Quality = 2 2 2 2 2

Chen analyses the evolution of the Visualization discipline from its infancy in the early 1990's.

(Chen 2003) C. Chen, Mapping Scientific Frontiers: The Quest for Knowledge Visualization, Springer Verlag, 2003.

http://www.dlib.org/dlib/september03/09bookreview.html
http://www.pages.drexel.edu/~cc345/books/msf.htm,

Keywords: Textbook Quality = 2 2 1 2 2

This is a good textbook about the scientific discovery process, and in particular about how scientific theories emerge and evolve. But it is not primarily about visualization -- visualization is used, but it is not the topic.

(Chen 2004a) C. Chen, Information Visualisation: Beyond the Horizon, Springer, 2004a.

http://www.amazon.com/exec/obidos/ASIN/1852331364/chaomeichensh-20/104-5163037-4934361,

Keywords: Textbook Quality = 2 2 2 2 2

This is the second edition of Chen's first book on visualization, and includes updated applications of information visualization such as: knowledge domain visualization, knowledge diffusion, representations of abrupt changes, social networks, virtual environments, and collaborative virtual environments. It discusses empirical findings, current topics, and emergent trends.

(Chen 2004b) C. Chen, "Searching for intellectual turning points: Progressive Knowledge Domain Visualization. " Proceedings of the National Academy of Sciences of the United States of America (PNAS) **101**: 5303-5310, 2004b.

http://www.pnas.org/cgi/reprint/0307513100v1.pdf

Keywords: Software Resource

Chen describes new visualization techniques for progressively visualizing the evolution of a knowledge domain. He shows that intellectual turning points can be identified using this type of visualization. This application, and this data source (citation indices) are distant from MISR, but there may be analogous applications in the search for terrorist activities.

(Chen 2005) C. Chen, "Top 10 Unsolved Information Visualization Problems" IEEE Computer Graphics and Applications, 2005.

http://www.pages.drexel.edu/~cc345/papers/cga2005.pdf

Keywords: Philosophical ; Requirements

Chen's list of the top 10 unsolved problems in visualization are: 1) Useability 2) Understanding elementary perceptual–cognitive tasks 3) Prior Knowledge 4) Education and Training 5) Intrinsic Quality Measures 6) Scaleability 7) Aesthetics 8) Paradigm shift from structures to dynamics 9) Causality, visual inference, and predictions 10) Knowledge domain visualization

(Chen 2006) C. Chen, *Curriculum Vitae*, Drexel University Philadelphia, online C.V. Accessed 2006.

http://www.pages.drexel.edu/~cc345/,

Keywords: Research Leader

Chaomei Chen is an Associate Professor in the College of Information Science and Technology at Drexel University, Philadelphia, USA {Chen, 2006 #387}. He is the author of Mapping Scientific Frontiers: The Quest for Knowledge Visualization, Information Visualization: Beyond the Horizon, and Visualizing the Semantic Web. He has invented ways to map out and visualize the development of academic disciplines, such as String Theory, using online citation indexes.

(Chen et al. 2000) C. Chen and M.P. Czerwinski, "Empirical evaluation of information visualizations: an introduction" Int. J. Human-Computer Studies **53**: 631-635, 2000.

http://www.pages.drexel.edu/~cc345/papers/ijhcs2000a.pdf

Keywords: MOE; Review Article Quality = 2 2 2 1 2

This is the introductory article for a special issue on measures of effectiveness in visualization systems. It is a useful overview of research that has been done in the subject, and includes a good, but not exhaustive, set of references.

(Chen et al. 2001) C. Chen, R.J. Paul and B. O'Keefe, "Fitting the jigsaw of citation: Information visualization in domain analysis" Journal of the American Society for Information Science and Technology **52**(4): 315-330, 2001.

(Chi 2000) E. Chi, "A Taxonomy of Visualization Techniques Using the Data State Reference Model" IEEE Symposium on Information Visualization 69-75, 2000.

http://www2.parc.com/istl/projects/uir/publications/items/UIR-2000-09-Chi-InfoVis2000-TaxonomyVisualization.pdf

Keywords: Architecture Quality = 2 2 1 1 2

The main topic of this paper - defining a taxonomy of visualizations based on a "data state model" - is rather academic and perhaps not of great interest for MISR. Embedded in the document, however, is a very useful table describing 29 different types of visualization, and giving references to example papers about them.

(Chinnock 2005) C. Chinnock, "It's a Jungle Out There", *Proc. PROCAMS 2005,* SanDiego, 2005.

http://www.procams.org/procams2005/extras/chinnock/InsightMedia-procams05.ppt,

Keywords: Display Hardware

Review of buying trends in large-format displays. Very much from a consumer-marketing perspective

(CIA 1995) CIA, "P1000 Strategic Plan for Information Visualization", Advanced Information Processing and Analysis Steering Group.

Keywords: Requirements; Defence *We have not been able to acquire a copy of this document.*

(CiteSeer 2006) CiteSeer, "Scientific Literature Digital Library". 2006.

http://citeseer.ist.psu.edu/,

This is a website providing searchable access to many scientific papers.

(Clark et al. 2004) P. Clark, R. Jones, M. Nixon and M. Taylor, "Data Information, Resource Discovery and Information Taxonomy for Presentation, Selection, and Design", *Proc. Visualisation for Defensive Information Warfare*, 2004.

http://www.visn-x.net/nx6/Syndicates/Syndicate2_and_5.html,

Keywords: Review Article ; Defence

The value of this very informal document lies in its delineation of the issues that are relevant to visualization of defence applications, albeit more for army than for navy applications. It may be a good starting point for analysing requirements.

(Clausner et al. 2005) T.C. Clausner and J.R. Fox, "A Framework and Toolkit for Visualizing Tacit Knowledge ", *Proc. 2005 International Conference on Intelligence Analysis,* McLean, VA 2005.

https://analysis.mitre.org/proceedings/Final_Papers_Files/161_Camera_Ready_Paper.pdf

Keywords: Uncertainty; Time and Space

This paper focuses on visual metaphors that represent temporal concepts about geospatial events and their qualitative uncertainties.

(Cockburn et al. 2006) A. Cockburn, C. Gutwin and J. Alexander, "Faster Document Navigation with Space-Filling Thumbnails", *Proc. ACM Conference on Human Factors in Computing Systems*, 2006.

http://hci.usask.ca/publications/2006/cockburn.pdf,

Keywords: Software Resource

This is a detailed description of a specific software tool. It appears to be useful for browsing large numbers of pages, for example in CANMARNET.

(Convertino et al. 2005) G. Convertino, C.H. Ganoe, W.A. Schafer, B. Yost and J.M. Carroll, "A Multiple View Approach to Support Common Ground in Distributed and Synchronous Geo-Collaboration", *Proc. Coordinated and Multiple Views in Exploratory Visualization*, p. 121-132, 2005.

http://cscl.ist.psu.edu/public/projects/ONRproject/index.html

Keywords: Collaboration

Explores the use of shared visualization for an analysis team that is geographically dispersed. They demonstrate strategies by which each team-member sees: 1) an "overview" showing where each team member is looking, 2) a simplified zoomed-in "team" view, and 3) a role-specific view with details required only by each specialist.

(Cribbin 2004) T. Cribbin, "InfoVis Links". Information Visualization, 2004.

http://people.brunel.ac.uk/~cssrtfc/iv_links.htm,

Keywords: Review Article Quality = 1 2 2 2 1

This is a good collection of links to other Information Visualization websites, under the headings: Research, IV Overviews, Commercial Systems, and Useful Software.

(Czerwinski et al. 2003) C.M. Czerwinski, G. Smith, T. Regan, B. Meyers, G. Robertson and G. Starkweather, "Toward Characterizing the Productivity Benefits of Very Large Displays" Human Computer Interaction, 2003.

http://research.microsoft.com/users/marycz/Interact2003productivityfinal.pdf

Keywords: Display Hardware Quality = 1 1 1 1 1

A preliminary study by Microsoft into whether productivity improves when working on much larger displays. It concludes that bigger is better.

(Czerwinski 2006) M. Czerwinski, *Curriculum Vitae*, Microsoft, online C.V. Accessed 2006.

http://research.microsoft.com/~marycz/,

Keywords: Research Leader

Mary Czerwinski is a Principal Researcher and manager of the Visualization and Interaction (VIBE) Research Group at Microsoft. She is executive vice-president of ACM SIGCHI and an editor of Information Visualization journal. Her speciality is human factors of large displays.

(Czerwinski et al. 2006) M. Czerwinski, G. Robertson, B. Meyers, G. Smith, D. Robbins and D. Tan, "Large Display Research Overview", *Proc. Conference on Human Factors in Computing Systems*, Montreal, 2006.

http://research.microsoft.com/research/vibe/pubs/CHI2006-largedisplays.pdf

Keywords: Display Hardware; Review Article Quality = 1 2 2 1 2

A good, and very current, review paper on how large displays are useful, and what challenges they pose for software design, such as keeping track of the cursor, distal access to windows and icons, dealing with bezels, window management, and task management.

(DARPA 2004) DARPA, "Bridging the Gap Awards", *Proc. DARPATech 2004 Symposium*, Anaheim, 2004.

http://www.darpa.mil/DARPAtech2004/awards.html,

Description of the Defence Advanced Research Project Agency's awards for technical achievements.

(Data Visualization Research Lab 2006) Data Visualization Research Lab, "Chart of the Future: Maximizing Mariner Effectiveness through Fusion of Marine and Visualization Technologies", 2006.

http://www.ccom.unh.edu/vislab/projects/ChartoftheFuture.html,

Keywords: Software Resource

This article describes a specific visualization tool suite for METOC -- bathymetry, tides, currents, etc. It is thus relevant to some of the more non-tactical roles of the future RMP.

(Davenport 2004) M. Davenport, "Feasibility and Architecture Report" RADARSAT-2 Self-Cueing Satellite Surveillance (SCSSR) Study **DND-RP-52-1139**, 2004.

Keywords: Coverage maps; Canadian; Time and Space Quality = 1 0 1 1 1

Figure 7-16 of this report shows one way that coverage can be visualized, taking into account potential ship motion. This type of graphic focuses on possible ship traffic along a known shipping route.

(Dempski et al. 2006) K. Dempski and B. Harvey, "Multi-User Display Walls: Lessons Learned", *Proc. Information Visualization and Interaction Techniques for Collaboration across Multiple Displays* Montreal, 2006.

Keywords: Display Hardware

A short paper with largely qualitative and anecdotal observations of customer interactions and expectations of large wall-mounted displays.

(Dennis et al. 1998) A.R. Dennis and T.A. Carte, "Using Geographical Information Systems for Decision Making: Extending Cognitive Fit Theory to Map-Based Presentations" Information Systems Research **9**(2): 194-203, 1998.

http://home.business.utah.edu/actme/7410/ME%204_15_02/Dennis%20Carte%20ISR%201998.pdf

Keywords: Human Factors Quality = 2 1 1 1 2

This article is written from a very analytical, very human-factors perspective. It examines how two equally-correct and equally-complete presentations of the same information are used differently for different tasks. Map-based presentations are more efficient for some tasks, and less efficient for other tasks, when compared to table-based presentations.

(Dodge 2004) M. Dodge, "An Atlas of Cyberspaces". CyberGeography.Org, 2004.

http://www.cybergeography.org/atlas/artistic.html,

Keywords: Information Landscapes ; Review Article Quality = 1 2 2 2 0

This is an excellent site for visually exploring various initiatives in visualization. It has scores of examples of very different images, all thoroughly linked to the labs where they originated.

(Ehlschlaeger et al. 1997) C. Ehlschlaeger, A. Shortridge and M. Goodchild, "Visualizing spatial data uncertainty using animation " Computers in Geosciences **23**(4): 387-395, 1997.

http://www.wiu.edu/users/cre111/older/CGFinal/paper.htm,

Keywords: Uncertainty

This is a seminal paper in the possible use of vibrations as an indicator of uncertainty. Unfortunately the application (topo maps) may not translate well to MISR applications.

(Eick 2000) S.G. Eick, "Visual Discovery and Analysis" IEEE Transactions on Visualization and Computer Graphics **6**(1): 44-58, 2000.

http://ieeexplore.ieee.org/xpl/abs_free.jsp?arNumber=841120,

Keywords: Software Resource Quality = 2 ? 1 ? ?

This is a description of "ADVIZOR", a software resource for visual information discovery.

(Eick et al. 2000) S.G. Eick and A. Karr, "Visual Scalability". NISS Technical Reports, 2000.

http://www.niss.org/technicalreports/tr106.pdf

Keywords: Overload ; Display Hardware

This is an important discussion of how some visualization strategies will scale well, and others will not. It discusses, for example, how information can be automatically aggregated when zooming out of a data view.

(Electronic Visualization Laboratory 2006) Electronic Visualization Laboratory, "CAVERN - The CAVE Research Network", 2006.

http://www.evl.uic.edu/core.php?mod=4&type=1&indi=9,

Keywords: Centre of Excellence ; Collaboration

This is a network of centers of excellence funded in part by the US National Science Foundation, looking at shared visualization over a network. They have, for example, a "Tele-Immersive Data Explorer" which is a collaborative immersive environment for querying and visualizing data from massive and distributed data-stores.

(Endsley et al. 2000) M.R. Endsley, R. Sollenberger and E. Stein, "Situation awareness: A comparison of measures", *Proc. Human Performance, Situation Awareness and Automation: User-Centered Design for the New Millennium*, Savannah, GA, 2000.

http://www.satechnologies.com/Papers/pdf/HPSAA2000-SAmeas.pdf

Keywords: MOE

Compares different Measures of Effectiveness for situational awareness. Main application is for air traffic control.

(Ericson et al. 2005) D. Ericson, J. Johansson and M. Cooper, "Visual Data Analysis using Tracked Statistical Measures within Parallel Coordinate Representations", *Proc. Coordinated and Multiple Views in Exploratory Visualization*, p. 42-53, 2005.

http://csdl2.computer.org/persagen/DLAbsToc.jsp?resourcePath=/dl/proceedings/cmv/&toc=comp/proceedings/cmv/2005/2396/00/2396toc.xml&DOI=10.1109/CMV.2005.21,

Keywords: Overload

Describes a method for decluttering the screen by extracting and displaying statistics in a separate view.

(Espinosa et al. 1999) O.J. Espinosa, C. Hendrickson and J.H.G. Jr., "Domain Analysis: A Technique to Design a User-Centered Visualization Framework ", *Proc. IEEE Symposium on Information Visualization*, p. 44, 1999.

http://csdl2.computer.org/persagen/DLAbsToc.jsp?resourcePath=/dl/proceedings/&toc=comp/proceedings/infovis/1999/0431/00/0431toc.xml&DOI=10.1109/INFVIS.1999.801856,

Keywords: Requirements

Addresses the need to do explicit domain analysis in the development of a visualization.

(Fekete 2005) J.-D. Fekete, "The InfoVis Toolkit Homepage". 2005.

http://ivtk.sourceforge.net/,

Keywords: Software Resource

This is the website for InfoVis, a Java Toolkit for information visualization. It includes scatter plots, time series, parallel coordinates, treemaps, icicle trees, node-link diagrams for trees and graphs and adjacency matrices for graphs. If this website is any indication, its strength is Treemaps and related methods for visualizing large tables of related data. It includes a moving lens (like the one by Idelix) for viewing a very large table of data.

(Fekete 2004) J. Fekete, "The Info Vis Toolkit", *Proc. 10th IEEE Symposium on Information Visualization*, p. 167-174, 2004.

http://www.lri.fr/~fekete/ps/ivtk-04.pdf

Keywords: Software Resource

The InfoVis toolkit is an important and widely cited software resource. It includes scatter plots, time series, parallel coordinates, treemaps, icicle trees, node-link diagrams for trees and graphs and adjacency matrices for graphs. This article gives an introduction to it.

(Fekete et al. 2002) J. Fekete and C. Plaisant, "Interactive Information Visualization of a Million Items", *Proc. IEEE Symposium on Information Visualization*, p. 117-124, 2002.

http://www.cs.umd.edu/hcil/millionvis/

Keywords: Tabular data ; Software Resource

This is an experiment to deploy tree-maps over a very large dataset, in order to understand the problems of scale that will be encountered.

(Finger et al. 2002) R. Finger and A.M. Bisantz, "Utilizing graphical formats to convey uncertainty in a decision-making task" Theoretical Issues in Ergonomic Science **3**(1): 1-25, 2002.

http://www.infofusion.buffalo.edu/reports/BISANTZ/papers/Bisantz-Finger%20Uncertainty%20Viz%20paper.pdf

Keywords: Uncertainty Quality = 1 1 2 1 1

This is one of the few papers that tries to visualize uncertainty. The authors modified the icons (smudged them) to indicate levels of uncertainty not in the locations of the objects, but in their identity. Significantly, the study found that users made better decisions as a result.

(Fisher et al. 2006) B. Fisher and J. Dill, "Cognitive Approaches for Studying Information Visualization and Interaction", *Proc. Information Visualization and Interaction Techniques for Collaboration across Multiple Displays* Montreal, 2006.

http://nvac.pnl.gov/ivitcmd_chi06/papers/sub15.pdf

Keywords: Human Factors

General discussion of one method for studying how people interact with a complex information environment.

(Foley 2000) J. Foley, "Getting There: The Top Ten Problems Left" IEEE Computer Graphics and Applications **20**(1): 66-68, 2000.

Keywords: Requirements Quality = 1 1 1 2 1

These are Foley's top ten problems: 1. Fill the gap between image-based and geometric modeling techniques. 2. Fill the gap between motion-capture animation and simulation/procedural animation. 3. Creative information visualization. 4. Automated creation of information and scientific visualizations. 5. Abstracting away from reality. 6. Display more pixels. 7. Display fewer pixels. 8. Unified graphics architectures. 9. User interfaces for 3D creativity. 10. Truly immersive virtual reality.

(Fua et al. 1999) Y.-H. Fua, M.O. Ward and E.A. Rundensteiner, "Navigating Hierarchies with Structure-Based Brushes", *Proc. INFOVIS*, p. 58-64, 1999.

Keywords: Software Resource

Describes a specific tool for navigating hierarchies using a "structure-based brush" and proximity-based coloring, which maps similar colors to data that are closely related within the structure.

(Furnas 1986) G. Furnas, "Generalized Fisheye Views", *Proc. Sigchi Conference on Human Factors in Computing Systems*, p. 16-23, 1986.

http://www.si.umich.edu/~furnas/Papers/FisheyeCHI86.pdf

Keywords: Software Resource

This may lay the foundation for fisheye lenses, but we have come a long way since. Interesting for historical reasons only.

(Gaither et al. 2004) K. Gaither, D. Ebert, K. Gaither, B. Geisler and D. Laidlaw, "Panel 2: In the Eye of the Beholder: The Role of Perception in Scientific Visualization", *Proc. 15th IEEE Visualization 2004*, p. 567-568, 2004.

http://csdl2.computer.org/persagen/DLAbsToc.jsp?resourcePath=/dl/proceedings/&toc=comp/proceedings/vis/2004/8788/00/8788toc.xml&DOI=10.1109/VISUAL.2004.77,

Keywords: Philosophical

Summary of a panel discussion.

(Gansner et al. 2005) E.R. Gansner, Y. Koren and S.C. North, "Topological Fisheye Views for Visualizing Large Graphs " IEEE Transactions on Visualization and Computer Graphics **11**(4): 457-468, 2005.

http://csdl2.computer.org/persagen/DLAbsToc.jsp?resourcePath=/dl/trans/tg/&toc=comp/trans/tg/2005/04/v4toc.xml&DOI=10.1109/TVCG.2005.66,

Keywords: Software Resource

Detailed extension of the classic fisheye lens technology into hard-to-view domains.

(Gelernter 2004) J. Gelernter, "Infoviz for Info Pros: Information Visualization Software Tools" Searcher **12**(9), 2004.

http://www.infotoday.com/searcher/oct04/gelernter.shtml,

Keywords: Review Article Quality = 0 2 0 2 0

This is a very accessible non-technical article about information visualization, and well worth a quick read. It provides links to a number of visualization initiatives, with its main focus on visualizations that will be useful for truly mass-markets such as internet browsers.

(Geroimenko et al. 2004) V. Geroimenko and C. Chen, Visualizing Information Using SVG and X3D: XML-based Technologies For The XML-based Web, Springer-Verlag, 2004.

http://www.amazon.com/gp/product/1852335769/102-8880711-9707369?v=glance&n=283155,

Keywords: Semantic Web Quality =? ? ? ? 2

This text is very specifically focused on the use of XML and ontologies for visualizing semantic content on the web. This will thus be an important reference for any MISR developments that require visualization of textual data or web pages, for example.

(Geroimenko et al. 2005) V. Geroimenko and C. Chen, Visualizing the Semantic Web : XML-based Internet and Information Visualization, Springer, 2005.

Keywords: Semantic Web

This text is very specifically focused on visualizing semantic content on the web. This will thus be an important reference for any MISR developments that require visualization of textual data or web pages, for example.

(Gibson 1987) J.J. Gibson, The Ecological Approach to Visual Perception, Boston, Houghton Mifflin, 1987.

http://www.temple.edu/ispr/abstracts/gibson79.html,

Keywords: Human Factors

This book seems to be more philosophical than scientific, and certainly out of the mainstream of Human Factors for visualization.

(Gibson 1984) W. Gibson, Neuromancer, New York, Ace Books, 1984.

Keywords: Information Landscapes Quality = 1 0 2 2 2

This is the book that invented the term "cyberspace" and gave the original description of dataspaces that could be visualized and navigated as landscapes. It remains useful for its description of how visualizing data as structures can aid in navigation and information discovery.

(Goodall et al. 2005) J.R. Goodall, W.G. Lutters, P. Rheingans and A. Komlodi, "Preserving the Big Picture: Visual Network Traffic Analysis with TN ", *Proc. IEEE Workshops on Visualization for Computer Security* p. 6, 2005.

http://userpages.umbc.edu/~jgood/publications/goodall-vizsec05.pdf

Keywords: Software Resource

The concepts developed in this paper appear to be very specific to the web-traffic application that they are applied to. If there is more general applicability, it is to demonstrate how important a dual focus (on details and the big picture) is.

(Google 2006a) Google, "Google Scholar Search Engine". 2006a.

http://scholar.google.com,

Specialized service from Google for searching academic papers and citations.

(Google 2006b) Google, "Search Engine", 2006b.

www.google.ca,

Primary search engine used in this research.

(Gouin et al. 2002) D. Gouin, P. Evdokiou and R. Vernik, "A Showcase of Visualization Approaches for Military Decision Makers", *Proc. Massive Military Data Fusion and Visualisation: Users Talk with Developers,* Halden, Norway, 2002.

http://vistg.net/Halden/presentations/Session%202/Showcase.ppt,

Keywords: Time and Space ; Tabular data

PowerPoint slides showing example visualizations of battlespace, information space, command options, network traffic, etc. We have provided independent links to all MISR-relevant techologies, in this bibliography.

(Graham 2006) M. Graham, "Information Visualization Links as of 19th May 2006". Martin Graham's Home Page, 2006.

http://www.dcs.napier.ac.uk/~marting/links.html,

Keywords: Review Article Quality = 1 2 2 1 1

This page provides a fairly comprehensive list of links related to Information Visualization journals, research and corporate interests.

(Graphics and Visualization Center 2006) Graphics and Visualization Center, "National Science Foundation Science and Technology Center", 2006.

http://www.cs.brown.edu/stc/,

Keywords: Centre of Excellence

This is the US National Science Foundation's primary center of excellence for visualization. It seems to be primarily focused on computer graphics, with some medical visualization activities.

(Grinstein et al. 2003) G. Grinstein, Z. Jacobson, K. Kesavadas, V. Taylor and D. Zeltzer, "Information Visualization Needs for Intelligence and Counter-Terror ", *Proc. Information Visualization for Counter-Terror Intelligence,* Pennsylvania State University, p. 10-11 March 2003, 2003.

http://www.visn-x.net/nx6/Syndicates/VISN-X_Syndicate4Report.doc,

Keywords: Requirements; Defence Quality = 1 2 1 0 2

This is the 2003 report from network-of-experts in Information Visualization for counter-terror intelligence. It sketches out the information architecture of the counter-terror intelligence domain, points out the visualization interaction styles that would be applied at various nodes in the counter-terror intelligence information architecture, and suggests an overall schema for the fusion of counter-terror intelligence.

(Gutwin 2006) C. Gutwin, *Curriculum Vitae*, University of Saskatchewan, online C.V. Accessed 2006.

http://hci.usask.ca/people/carl.shtml,

Keywords: Research Leader; Canadian

Gutwin's main research areas are Computer-Supported Cooperative Work, Information Visualization, and Information Retrieval. He is a specialist in Fisheye Lenses.

(Gutwin et al. 2004) C. Gutwin and C. Fedak, "A Comparison of Fisheye Lenses for Interactive Layout Tasks", *Proc. Graphics Interface* London, Ontario, Canada p. 213 - 220 2004.

http://hci.usask.ca/publications/2004/layout-gi04.pdf

Keywords: Software Resource ; Canadian Quality = 1 2 2 1 2

Detailed study of a specific visualization tool - the fisheye lens. Gutwin has written many papers on Fisheye Lenses.

(Hall 1999) T. Hall, "CIA's Baseline Study for Intelligence Community Collaboration: Final Report". 1999.

http://collaboration.mitre.org/prail/IC_Collaboration_Baseline_Study_Final_Report/toc.htm,

Keywords: Requirements; Collaboration; Defence

A baseline study by Mitre Corp to examine policy, procedural, and cultural barriers to interagency collaboration across the Intelligence Community. Key areas of concern include a cultural tradition inconsistent with information sharing; lack of common goals for collaboration across the community; lack of trust in organizations, individuals, and systems; lack of perceived mutual benefit to participate in collaboration efforts; and inadequate reward systems to support collaboration. The relevance to MISR is in understanding cultural barriers to collaborative intelligence sharing and visualization.

(Hao et al. 2005) M.C. Hao, U. Dayal, D.A. Keim and T. Schreck, "Importance-Driven Visualization Layouts for Large Time Series Data ", *Proc. IEEE Symposium on Information Visualization*, p. 27, 2005.

http://dbvis.inf.uni-konstanz.de/~schreck/tsprojects/papers/infovis05.pdf

Keywords: Software Resource ; Time and Space

This is an interesting fusion of time-series information with tree maps so that the space used for each time series reflects the relative importance of the information. It is a very specific visualization tool, that will only be of interest to MISR if a correspondingly specific visualization requirement crops up.

(Hara et al. 1995) K. Hara and S. Nakamura, "A comprehensive assessment system for the maritime traffic environment " Safety Science **19**(2-3): 203-215, 1995.

http://www.csa.com/partners/viewrecord.php?requester=gs&collection=ENV&recid=3827750,

Keywords: Time and Space; Uncertainty

This report may offer some examples of how to visualize risk in maritime traffic flow.

(Harris 1999) R.L. Harris, Information Graphics: A Comprehensive Illustrated Reference, Oxford, Oxford University Press, 1999.

http://www.amazon.com/gp/product/0195135326/102-8880711-9707369?v=glance&n=283155,

Keywords: Graphics Quality = 1 0 1 2 2

This book is primarily intended as a reference for people producing textual reports. It constrains itself to two-dimensional static presentations of quantitative information.

(Healey et al. 1993) C.G. Healey, K.S. Booth and J.T. Enns, "Harnessing Preattentive Processes for Multivariate Data Visualization ", *Proc. Graphics Interface*, p. 107-117, 1993.

http://www.csc.ncsu.edu/faculty/healey/download/gi.93.pdf

Keywords: Software Resource ; Human Factors

These tools showcase the use of "preattentive cues" to add new dimensions to data visualization. We are used to using, for example, spatial dimensions, orientation, and colour to provide all the axes for a representation, so the addition of new axes may be very important.

(Hengst et al. 2004) M.d. Hengst, M. McQuaid and J. Zhu, "Impact of Time-Based Visualization on Situation Awareness ", *Proc. 37th Annual Hawaii International Conference on System Sciences,* Hawaii, 2004.

http://csdl2.computer.org/persagen/DLAbsToc.jsp?resourcePath=/dl/proceedings/&toc=comp/proceedings/hicss/2004/2056/01/2056toc.xml&DOI=10.1109/HICSS.2004.1265150,

Keywords: Time and Space; MOE

This paper tests visualization strategies for improving situation awareness, using a non-MISR application. It also provides a detailed account of situation awareness theory and uses it to explain the effect of the visualization on perceptions of facts, comprehension of the situation, and projection of near term status.

(Hennessy et al. 2003) J.L. Hennessy, D.A. Patterson and H.S. Lin, Information Technology for Counterterrorism: Immediate Actions and Future Possibilities, 2003.

http://bob.nap.edu/html/IT_counterterror/,

Keywords: Requirements; Defence

Identifies the need for "research on human-computer interaction in the areas of query formulation and visualization" and specifically " techniques that are effective for visualizing huge amounts of dynamic information derived from unstructured data about people, places and events."

(Heuer 1999) R.J. Heuer, Psychology of Intelligence Analysis, Washington, D.C., USGPO, 1999.

http://www.cia.gov/csi/books/19104/index.html,

http://www.cia.gov/csi/books/19104/index.html

Keywords: Requirements; Defence

This book is an introspective analysis of how intelligence professionals engage information and try to make sense of it, and the things that get in the way of doing that effectively. It also makes suggestions about how they could do this more effectively.

(Hew 2003a) P.C. Hew, "A MATLAB Toolbox for Surveillance Operations Analysis". DSTO Publications, 2003a.

http://www.dsto.defence.gov.au/publications/2553/DSTO-TN-0458.pdf

Keywords: Coverage Maps ; Unknown

This overlaps Hew's conference paper, but with some added detail on how things work. As in the conference paper, the illustrations are not as clear as they should be.

(Hew 2003b) P.C. Hew, "Visualisation of Surveillance Coverage by Latency Mapping ", *Proc. Australasian Symposium on Information Visualization*, Adelaide, 2003b.

Keywords: Coverage Maps ; Unknown

This is a key document and has exact applicability to MISR. It discusses how to visualize how periodic coverage (e.g. from an overflight) fades with time. Latency mapping is built on the modelling of surveillance assets through swaths, geographic regions monitored over intervals of time. These swaths are projected in space to generate a scan history, which is then projected in time to generate a latency history. The latency history is viewed through animation, with short latency degrading to long latency by solid colours fading to transparent.

(Horn 2005) R.E. Horn, "Connecting the Smudges: How Analytic Info - Murals May Be of Help in Dealing With Social Messes", *Proc. 2005 International Conference on Intelligence Analysis*, McLean, VA 2005.

https://analysis.mitre.org/proceedings/Final_Papers_Files/38_Camera_Ready_Paper.pdf

Keywords: Uncertainty ; Display Hardware

A concept paper on whether one needs really large-format (4' x 16') "murals" in order to adequately display really complex "global" issue problems. Raises six explicit challenges: represent context; represent multiple strategies; in issue management, represent serious and complex debates; understand ideologies; get a more comprehensive picture of unknowns; display multiple points of view.

(Hornbæk et al. 2002) K. Hornbæk, B.B. Bederson and C. Plaisant, "Navigation patterns and usability of zoomable user interfaces with and without an overview " ACM Transactions on Computer-Human Interaction (TOCHI) **9**(4): 362 - 389, 2002.

Keywords: Human Factors

Specific research into zoomable user interfaces: does an overview help users or not?

(Hosbond et al. 2003) J.H. Hosbond, S. Saltenis and R. Ortoft, "Indexing Uncertainty of Continuously Moving Objects ", *Proc. 14th International Workshop on Database and Expert Systems Applications*, p. 911, 2003.

http://csdl2.computer.org/persagen/DLAbsToc.jsp?resourcePath=/dl/proceedings/&toc=comp/proceedings/dexa/2003/1993/00/1993toc.xml&DOI=10.1109/DEXA.2003.1232137,

Keywords: Uncertainty

This article addresses the problem of how to index a moving object in the presence of uncertainty, which would have to be addressed if visualizing such an object before knowing whether an object is within the field of view or not. Unfortunately the article does not address the visualization of the uncertainty.

(Howard et al. 1996) D. Howard and A. MacEachren, "Interface Design for Geographic Visualization: Tools for Representing Reliability" Cartography and Geographic Information Systems **23**(2): 59-77, 1996.

http://www.geovista.psu.edu/publications/others/howard/howmac96.html,

(Hutchins 1996) E. Hutchins, Cognition in the Wild, MIT Press, 1996.

http://cscs.umich.edu/~crshalizi/reviews/cognition-in-the-wild/,

Keywords: Philosophical

This is a philosophical book about the nature and process of cognition, using an extended metaphor of the navigation of a ship. The introduction seems rather flaky, but the book is published by the MIT Press, which is not known for being flaky, so we suspect there is something useful here. It is, however, not directly on the topic of visualization.

(IEEE 1995-2006) IEEE, "Transactions on Visualization & Computer Graphics ", IEEE Computer Society, 1995-2006.

http://csdl2.computer.org/persagen/DLPublication.jsp?pubtype=t&acronym=tg,

Keywords: Journal Stream Quality = 2 2 2 2 2

This is the premier journal for information visualization. Editorial focus is on computer graphics and visualization techniques, systems, software, hardware, and user interface issues. Specific topics include: algorithms, techniques and methodologies; systems and software; user studies and evaluation; perception, human computer interaction and user interfaces; visual analysis and visual analytics; high-dynamic range imaging and display, 3D display technology, multi-spectral displays; and applications of graphics and visualization.

(IEEE Computer Society 1986-2006) IEEE Computer Society. IEEE Visualization Conference (VIS), 1986-2006.

http://www.computer.org/portal/site/store/menuitem.41cf17dc879177c86ee948ce8bcd45f3/index.jsp?&pName=store_level1&path=store/p2005a&file=r0232.xml&xsl=generic.xsl&,

Keywords: Conference Stream

The oldest IEEE conference on scientific visualization, and just as relevant as InfoVis for MISR applications.

(IEEE Computer Society 1995-2006) IEEE Computer Society. IEEE Symposium on Information Visualization (InfoVis), 1995-2006.

http://www.computer.org/portal/site/store/menuitem.41cf17dc879177c86ee948ce8bcd45f3/index.jsp?&pName=store_level1&path=store/p2005a&file=r0233.xml&xsl=generic.xsl&,

Keywords: Conference Stream Quality = 2 2 2 1 2

InfoVis is the pre-eminent conference on information visualization. The central design challenge in infovis is designing a cognitively useful spatial mapping of a dataset that is not inherently spatial.

(IEEE Computer Society 1997-2006) IEEE Computer Society. International Conference on Information Visualisation (IV), 1997-2006.

http://www.computer.org/portal/site/store/menuitem.41cf17dc879177c86ee948ce8bcd45f3/index.jsp?&pName=store_level1&path=store/p2005&file=p2397.xml&xsl=generic.xsl&,

Keywords: Conference Stream

IV is IEEE's international conference on information visualization, and thus in many ways parallels InfoVis.

(IEEE Computer Society 2003-2006) IEEE Computer Society. Coordinated & Multiple Views in Exploratory Visualization, 2003-2006.

http://csdl2.computer.org/persagen/DLAbsToc.jsp?resourcePath=/dl/proceedings/&toc=comp/proceedings/cmv/2005/2396/00/2396toc.xml,

Keywords: Conference Stream

Small conference held in conjunction with InfoVis. Focuses on all aspects of multiple-view techniques including: multiform views, tight coupling, linked dynamic interaction, multiple views for interactive steering, and spreadsheet based visualization techniques.

(Info Vis Wiki 2006) Info Vis Wiki, "Main Page", Accessed 2006.

http://www.infovis-wiki.net/index.php/Main_Page,

Keywords: Review Article

This Wiki is immature and is thus spotty - some pages are much better than others. It appears that the visualization software industry has not embraced it as a marketing tool. It gives a useful set of links to researchers home pages, particularly European labs.

(Irani et al. 2006) P. Irani, C. Gutwin and X.D. Yang, "Improving Selection of Off-Screen Targets with Hopping", *Proc. Computer-Human Interaction* Montréal, 2006.

http://hci.usask.ca/publications/2006/irani.pdf

Keywords: Software Resource ; Canadian

This is a specific visualization strategy, in this case useful for being aware of, and jumping to, objects that are off-screen.

(Irani et al. 2003) P. Irani and C. Ware, "Diagramming information structures using 3D perceptual primitives " ACM Transactions on Computer-Human Interaction (TOCHI) **10**(1): 1 - 19, 2003.

(Jimenez et al. 2003) W.H. Jimenez, W.T. Correa, C.T. Silva and B. Baptista, "Visualizing Spatial and Temporal Variability in Coastal Observatories ", *Proc. 14th IEEE Conference on Visualization*, p. 75, 2003.

http://www.cse.ogi.edu/~csilva/papers/vis2003.pdf

Keywords: METOC Quality = 1 1 0 1 1

Visualization tools for ocean currents, salinity, expected drift, etc. using colour-coded maps. Slightly relevant to MISR but not a great leap forward in technology.

(Johnson et al. 1991) B. Johnson and B. Shneiderman, "Tree-Maps: A Space Filling Approach to the Visualization of Hierarchical Information Structures", *Proc. 2nd IEEE Conference on Visualization* p. 284-291, 1991.

http://www.cs.umd.edu/class/spring2001/cmsc838b/presentations/Steve_Betten/TreeMap.ppt

Keywords: Tabular data

Seminal paper on the used of tree maps for hierarchical data. This paper is very heavily cited, suggesting that it played a key role as an inspiration for other types of visualization.

(Johnson 1995a) C. Johnson, "Temporal Aspects Of Usability: Supporting The Empirical Analysis Of Interactive Behaviour", *Proc. CHI '95*, 1995a.

http://www.dcs.gla.ac.uk/~johnson/papers/hci95.html,

Keywords: Human Factors

An overview of the Temporal Aspects of Usability (TAU) project. No research results are reported.

(Johnson 1995b) C. Johnson, "Temporal Aspects of Usability; Assessing the Impact of Time on User Interface Design", *Proc. Computer-Human Interaction*, 1995b.

http://acm.org/sigchi/bulletin/1996.2/Chris-Johnson.html,

Keywords: Human Factors

This paper describes human factors research into temporal aspects of the user interface, such as delays in response time, and co-arrival of multiple info-bites. It mainly describes how a lab has been set up to measure these things. No conclusions are drawn.

(Johnson et al. 2006) C. Johnson, R. Moorhead, T. Munzner, H. Pfister, P. Rheingans and T.S. Yoo, NIH-NSF Visualization Research Challenges Report, 2006.

http://www.sci.utah.edu/vrc2005/vrc-report-vis05.pdf

Keywords: Requirements

This document is primarily concerned with visualization for medical and biological sciences, but it does give some insight into the state of the art of the field in general, and it is very current. It is in many ways parallel to "Illuminating the Path" put out by NVAC.

(Johnson et al. 2004) G. Johnson, D. Ebert, C. Hansen, D. Kirk, B. Mark and H. Pfister, "Panel 3: The Future Visualization Platform ", *Proc. 15th IEEE Visualization* p. 569-571, 2004.

http://csdl2.computer.org/persagen/DLAbsToc.jsp?resourcePath=/dl/proceedings/&toc=comp/proceedings/vis/2004/8788/00/8788toc.xml&DOI=10.1109/VISUAL.2004.78,

Keywords: Philosophical

Panelists at VIS'04 offer their views on the direction of future graphics hardware and its potential impact on visualization, and on the nature of advanced visualization-related tools and techniques.

(Jonker et al. 2005) D. Jonker, W. Wright, D. Schroh, P. Proulx and B. Cort, "Information Triage with TRIST ", *Proc. Intelligence Analysis Conference,* Washington, DC., 2005.

http://www.oculusinfo.com/papers/Oculus_TRIST_Final_Distrib.pdf

Keywords: Canadian; Overload; Requirements Quality = 1 1 1 2 2

This paper starts with useful observations of analyst's challenges in information retrieval, mainly reviewing vast numbers of documents. The paper describes a new tool "TRIST" for more efficiently searching the web for more relevant information, and quantifies how much it improved productivity. This was part of ARDA's, "Novel Intelligence From Massive Data" program.

(Kapler et al. 2004a) T. Kapler and W. Wright, "GeoTime Information Visualization ", *Proc. Symposium on Information Visualization* p. 25-32, 2004a.

http://doi.ieeecomputersociety.org/10.1109/INFVIS.2004.27,

Keywords: Time and Space ; Canadian Quality = 1 1 2 2 2

Another presentation of the GeoTime visualization software and underlying analytical foundations for it. This is important for MISR.

(Kapler et al. 2004b) T. Kapler and W. Wright, "Visualization for Tracking Battlefield Events in Time and Space for C2 ", *Proc. Command and Control Research and Technology Symposium*, 2004b.

http://www.dodccrp.org/events/2004/CCRTS_San_Diego/CD/papers/137.pdf

Keywords: Time and Space

Another presentation of the GeoTime visualization software and underlying analytical foundations for it. This is important for MISR.

(Keller et al. 2005) T. Keller and S.O. Tergan, Knowledge and Information Visualization - Searching for Synergies, Springer, 2005.

http://www.amazon.com/gp/product/3540269215/102-8880711-9707369?n=283155,

Keywords: Textbook

This is an edited compilation of articles under the following headings: 1) Knowledge Visualization, 2) Information Visualization, 3) Visualizing Knowledge and Information for Fostering Learning and Instruction, 4) Knowledge-Oriented Organization of Information for Fostering Information Use. There is an introductory article by Colin Ware.

(Kim 2004) S. Kim, "Conveying shape with texture: experimental investigations of texture's effects on shape categorization judgments", *Proc. Visualization and Computer Graphics, IEEE Transactions on* 2004.

http://ieeexplore.ieee.org/search/freesrchabstract.jsp?arnumber=1298804&isnumber=28852&punumber=2945&k2dockey=1298804@ieeejrns&query=%28symposium+on+information+visualization%29+%3Cin%3E+metadata&pos=0,

Keywords: Human Factors

Human factors study of how well shape can be communicated by different textures.

(Kirschenbaum et al. 1995) S.S. Kirschenbaum, W.D. Gray and R.M. Young, "Cognitive Architectures and HCI", *Proc. CHI '95*, 1995.

http://www.rpi.edu/~grayw/pubs/papers/KGY96_SCBul.pdf

Keywords: Human Factors ; Architecture

Describes models for cognitive processing as it applies to human-computer interactions.

(Kitsiou et al. 2001) D. Kitsiou, X.d. Madron, A. Durrieu and A. Pedro, "Development of a Data Visualization and Analysis Tool to Study the Particle Dynamics in the Coastal Zone" Marine Pollution Bulletin **43**(7): 262, 8 p., 2001.

Keywords: METOC

Describes the development of IDL tools for visualizing METOC data in the coastal zones.

(Kohlhammer et al. 2004) J. Kohlhammer and D. Zeltzer, "Towards a visualization architecture for time-critical applications", *Proc. 9th international conference on Intelligent user interface*, p. 271-273, 2004.

http://citeseer.ist.psu.edu/rd/51278349%2C662393%2C1%2C0.25%2CDownload/http://citeseer.ist.psu.edu/cache/papers/cs/30314/http:zSzzSzwww.iuiconf.orgzSz04pdfzSz2004-002-0021.pdf/kohlhammer04towards.pdf

Keywords: Architecture ; Real-Time

Specifically addresses implementation challenges for real-time systems, where new information must be integrated with background information. More of an implementation study than basic research.

(Krüger 1998) A. Krüger, "Visualizing information spaces: Automatic graphical abstraction in intent-based 3D-illustrations ", *Proc. Working Conference on Advanced Visual Interfaces* p. 47 - 56 1998.

http://citeseer.ist.psu.edu/cache/papers/cs/1823/http:zSzzSzwww.dfki.dezSz~kruegerzSzavi98.pdf/kruger98automatic.pdf

Keywords: Overload

This paper reviews possible ways to automatically and selectively simplify graphical presentations in order to de-clutter a visualization and draw the user's attention to the relevant information.

(Laramee 2002) R.S. Laramee, "Rivalry and interference with a head-mounted display" ACM Transactions on Computer-Human Interaction (TOCHI) **9**(3): 238 - 251, 2002.

http://portal.acm.org/citation.cfm?id=568513.568516&coll=ACM&dl=ACM&idx=568513&part=periodical&WantType=periodical&title=ACM%20Transactions%20on%20Computer%2DHuman%20Interaction%20%28TOCHI%29&CFID=74432608&CFTOKEN=9960560#review,

Keywords: Display Hardware ; Human Factors

Human Factors analysis of what causes visual interference in a head-mounted display.

(Laramee et al. 2001) R.S. Laramee and C. Ware, "Visual interference with a transparent head mounted display", *Proc. Conference on Human Factors in Computing Systems*, Seattle, Washington p. 323-324, 2001.

http://www.vrvis.at/scivis/hmd/laramee01visual.pdf,

Keywords: Display Hardware ; Human Factors

Human Factors analysis of what causes visual interference in a head-mounted display.

(Lima 2006) M. Lima, "Visual Complexity". 2006.

http://www.visualcomplexity.com/vc/,

This is a very extensive blog and repository that intends to be a unified resource space for anyone interested in the visualization of complex networks. Information visualization links and articles include the following topics (with number of links): Art (20), Biology (32), Business Networks (19), Computer Systems (18), Food Webs (7), Internet (26), Knowledge Networks (63), Multi-Domain Representation (23), Others (21), Pattern Recognition (11), Social Networks (44), Transportation Networks (25), World Wide Web (33).

(Livnat et al. 2005a) Y. Livnat, J. Agutter, S. Moon and S. Foresti, "Visual Correlation for Situational Awareness", *Proc. 2005 IEEE Symposium on Information Visualization*, p. 13, 2005a.

http://www.sci.utah.edu/publications/yarden05/VisAware.pdf

Keywords: Time and Space

This is a helpful and potentially important description of one way to visualize "Situational Awareness" and appears to be immediately applicable to MISR.

(Livnat et al. 2005b) Y. Livnat, J. Agutter, S. Moon and S. Foresti, "Visual Correlation for Situational Awareness ", *Proc. Infovis 95,* Minneapolis, MN (USA), , 2005b.

http://www.sci.utah.edu/publications/yarden05/VisAware.pdf

Keywords: Time and Space ; Software Resource

Interesting approach to using visualization for Situation Awareness that may be directly applicable to MISR. Nice clean diagrams.

(Llinas et al. 2002) J. Llinas and K. Kesavadas, "Visualizing Non-Physical, Logical Constructs for Command Decision-Making Support", *Proc. Massive Military Data Fusion and Visualisation: Users Talk with Developers*, Halden, Norway, 2002.

http://vistg.net/Halden/presentations/Session%204/Llinas2002.ppt,

Keywords: Time and Space ; Tabular Data

An authoritative PowerPoint presentation on using visualization to communicate "higher level" data fusion by James Llinas who "wrote the book" on data fusion. He introduces the"Event Wall" by Secure Decisions, Inc. and "Starlight" by Pacific Northwest National Labs.

(Lymon et al. 2003) P. Lymon and H.R. Varian, "How Much Information". 2003.

http://www.sims.berkeley.edu/how-much-info,

Keywords: Requirements Quality = 1 0 2 1 1

This study is an attempt to measure how much information is produced in the world each year. It looks at several media and estimate yearly production, accumulated stock, rates of growth, and other variables of interest. It's relevance to MISR is primarily as background information for scaling of information systems.

(MacEachren 2006) A. MacEachren, *Curriculum Vitae*, Pennsylvania State University, Department of Geography, online C.V. Accessed 2006.

http://www.geog.psu.edu/people/maceachren/,

Keywords: Research Leader

MacEachren has a background in cartography and environmental cognition and has worked for years in geographic representation and geovisualization. He is specifically interested in human mental representation of space and space-time, integration of geographic visualization with other knowledge construction methods, GeoVirtual environments, and geocollaboration. He wrote the seminal text "How Maps Work: Representation, Visualization and Design" that developed a cognitive-semiotic theoretical perspective from which to address these and related issues.

(MacEachren 1995) A.M. MacEachren, How Maps Work: Representation, Visualization and Design, Guilford Press, 1995.

http://www.amazon.com/gp/product/0898625890/104-0056607-2719103?v=glance&n=283155,

Keywords: Textbook ; Time and Space ; Uncertainty ; Philosophical Quality = 2 2 2 0 2

This book starts with a human factors analysis of how people ingest geographic information (where we attend, perceptual categorization), builds on that a theory of how maps are understood (knowledge schematia, cognitive representations), and then analyses the semiotics (use of symbols and icons) of maps. Section III specifically looks at maps as Space-Time visualization systems, including an analysis of the use of features such as shape, orientation, colour, and time. Chapter 10 "Should We Believe What We See?" touches on the problem of representing uncertainty. The book is written largely in the passive voice, using arcane academic language, and is thus difficult to read.

(MacEachren et al. 2004) A.M. MacEachren, M. Gahegan and W. Pike, "Visualization for constructing and sharing geo-scientific concepts" Proc Natl Acad Sci **101**: 5279–5286, 2004.

http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=387308,

Keywords: Software Resource Quality = 1 1 1 1 2

This article describes the "HERO Collaboratory" research software, developed in GeoVISTA Studio, and some of the strategies that it uses to co-display abstract and geo-based information. It illustrates them by visualizing collaboration in the development of new scientific theories.

(MacEachren et al. 2001) A.M. MacEachren and M.J. Kraak, "Research Challenges in Geovisualization" Cartography and Geographic information Science **28**(1): 3-12, 2001.

http://www.highbeam.com/doc/1G1:72433172/Research+Challenges+in+Geovisualization.html?refid=SEO,

(MacKinlay 1986) J. MacKinlay, "Automating the design of graphical presentations of relational information" ACM Transactions on Graphics **5**(2): 110-141, 1986.

http://portal.acm.org/citation.cfm?id=22950,

(Mackinlay 2006) J.D. Mackinlay, *Curriculum Vitae*, PARC, online C.V. Accessed 2006.

http://www2.parc.com/istl/members/mackinlay/,

Keywords: Research Leader

Jock Mackinlay is a leader in information visualization, particularly for abstract data spaces, and works out of Xerox PARC. He collaborated with the User Interface Research Group to develop many novel applications of computer graphics for information access, coining the term "Information Visualization". He co-invented a number of visualizing techniques, including Cone Trees and Perspective Walls. His current research is exploiting advances in flat panel displays and graphics cards that enable personal computers with 6-8 monitors and may also eliminate seams.

(Mackinlay et al. 1991) J.D. Mackinlay, G.G. Robertson and S.K. Card, "The perspective wall: detail and context smoothly integrated", *Proc. SIGCHI conference on Human factors in computing systems: Reaching through technology,* New Orleans, p. 173-176, 1991.

(MacMillan 2006) P. MacMillan. Information Visualization Palgrave MacMillan, 2006.

http://www.graphicslink.co.uk/IV06/,

Keywords: Journal Stream

Associated with IEEE Computer Society (see http://www.graphicslink.co.uk/IV06/)

(Majumder et al. 2005) A. Majumder and R. Raskar. IEEE International Workshop on Projector-Camera Systems, San Diego, 2005.

http://www.procams.org/procams2005/,

Keywords: Display Hardware

Annual conference with heavy leadership from industry to explore new uses of display technology.

(May et al. 2006) R. May and B. Baddeley, "Visual Analytics: Large and Small Display Environments". National Visualization and Analytics Center, 2006.

http://nvac.pnl.gov/ivitcmd_chi06/papers/may.pdf

Keywords: Display Hardware ; Human Factors

This lab uses cameras to track hand gestures, pointing devices, etc. to gather quantitative data on how users interact with large-format screens.

(McCormick et al. 1987) B.H. McCormick, T.A. DeFanti and M.D. Brown, "Special Issue: Visualization in Scientific Computing" Computer Graphics **21**(6), 1987.

Keywords: Review Article

Seminal Report that "Set the Agenda" for computer-aided visualization.

(McGuffin et al. 2005) M.J. McGuffin and R. Balakrishnan, "Fitts' law and expanding targets: Experimental studies and designs for user interfaces " ACM Transactions on Computer-Human Interaction (TOCHI) **12** (4): 388 - 422 2005.

http://portal.acm.org/ft_gateway.cfm?id=1121115&type=pdf&coll=ACM&dl=ACM&CFID=74432608&CFTOKEN=9960560

Keywords: Human Factors

Looks at making it easier for operators to click on a target, by making the target icon larger as the cursor approaches it.

(Merrick et al. 2003) J.R.W. Merrick, V. Dinesh, A. Singh, J.R.v. Dorp and T.A. Mazzuchi, "Propagation of Uncertainty in a Simulation-Based Maritime Risk Assessment Model Utilizing Bayesian Simulation Techniques. " *Proc. 2003 Winter Simulation Conference*, 2003.

Keywords: Uncertainty

A useful paper for visualizing uncertainty and collision risk in ship traffic. Although this paper's primary topic is the calculation of risk probabilities, it then examines the answers using effective and interesting visualization techniques. Four movies of the simulations are available at http://www.people.vcu.edu/~jrmerric/SFBayMovies/ and illustrate the visualization strategies.

(Mezzanotte 1995) M. Mezzanotte, "Temporal Aspects of Usability: Including Time in the Notion of Interactor", *Proc. CHI '95*, 1995.

http://www.sigchi.org/bulletin/1996.2/Fabio-Paterno.html,

Keywords: Human Factors

This is a very technical Human Factors paper that extends HF models for describing interactive systems. Probably not very helpful for MISR algorithm development.

(Mitre Corporation 2005) Mitre Corporation. International Conference on Intelligence Analysis, 2005.

https://analysis.mitre.org/proceedings_agenda.htm#papers,

Keywords: Conference Stream ; Review Article

Interesting insights into how the Intelligence community searches for interpretations of their data.

(Moere 2004) A.V. Moere, "Time-Varying Data Visualization Using Information Flocking Boids ", *Proc. IEEE Symposium on Information Visualization* p. 97-104, 2004.

http://www.arch.usyd.edu.au/~andrew/content/publications/infovis04.pdf

Keywords: Software Resource; Time and Space Quality = 2 1 1 2 1

Research into the use of "information flocking" to take advantage of the (pre-cognitive) ability of the human vision system to detect and track a group of co-moving objects ("boids") in a complex scene, and the (cognitive) ability to recognize large-scale changes in the structure of a "flock of boids." This is a good example of off-the-beaten-track research that broadens the field.

(Mould et al. 2004) D. Mould and C. Gutwin, "The Effects of Feedback on Targeting with Multiple Moving Targets", *Proc. Graphics Interface*, p. 114-121, 2004.

http://hci.usask.ca/publications/2006/cockburn.pdf,

Keywords: Human Factors ; Overload ; Canadian

Human factors analysis of how "targeting" (i.e. selecting an icon on the screen) gets more difficult as the icons move faster and become more dense. It suggests that visual feedback (in this case marking the selected target with an X) helps

(Munzner et al. 2003) T. Munzner, F. Guimbretiere, S. Tasiran, L. Zhang and Y. Zhou, "TreeJuxtaposer: Scalable Tree Comparison using Focus and Context with Guaranteed Visibility" ACM Transactions on Graphics (TOG) archive **22**(3): 453 - 462 2003.

http://www.cs.ubc.ca/labs/imager/tr/pdf/munzner2003a.pdf

Keywords: Tabular data ; Canadian

This is a specific visualization tool for objects that are members of multiple hierarchical structures at the same time. It may have value as a specific element of a larger MISR application.

(Nacenta et al. 2006) M. Nacenta, S. Sallam, B. Champoux, S. Subramanian and C. Gutwin, "Perspective Cursor: Perspective-based Interaction for Multi-display Environments ", 2006.

(National Science Foundation 2006) National Science Foundation, "Visualization: a Way to See the Unseen", 2006.

http://www.nsf.gov/about/history/nsf0050/pdf/visualization.pdf,

Keywords: Review Article

This is an advertising brochure from the National Science Foundation, promoting (presumably to their funding agencies) the value of visualization and computer graphics research in the USA. It gives a very brief overview of the history of the field, and a summary of its potential applications. That summary does not mention military applications. It identifies Brown University (www.cs.brown.edu/stc) as their primary center of excellence.

(NATO 2002) NATO. Massive Military Data Fusion and Visualisation: Users Talk with Developers, Norwegian Defence Logistics and Management College, Halden, Norway, 2002.

http://vistg.net/Halden/Programme.html,

Keywords: Conference Stream

Conference starting to address military requirements for data fusion and visualization.

(Nooface 2006) Nooface, "In search of the Post-PC Interface". 2006.

http://nooface.net/,

Keywords: Review Article

This is a web magazine focusing on next-generation GUI concepts. Articles are contributed from a variety of authors.

(Nowell et al. 2002) L. Nowell, R. Schulman and D. Hix, "Graphical Encoding for Information Visualization: An Empirical Study ", *Proc. IEEE Symposium on Information Visualization*, p. 43, 2002.

http://csdl2.computer.org/persagen/DLAbsToc.jsp?resourcePath=/dl/proceedings/&toc=comp/proceedings/infovis/2002/1751/00/1751toc.xml&DOI=10.1109/INFVIS.2002.1173146,

Keywords: Human Factors

This is a presentation of some of the results from Nowell's thesis, which is cited below.

(Nowell 1997) L.T. Nowell, "Graphical Encoding for Information Visualization: Using Icon Color, Shape, and Size To Convey Nominal and Quantitative Data", *Proc. Computer Science*, 1997.

Keywords: Human Factors

Detailed analysis of how to use Icons effectively. Extensive citations. Most of the information cited is summarized and indexed more effectively in Ware's textbook.

(NVAC 2006) NVAC, "National Visualization and Analytics Center", 2006.

http://nvac.pnl.gov/,

Home page for NVAC, a major center of excellence for visualization.

(O'Donnell 1995) P. O'Donnell, "How machine delays change user strategies", *Proc. CHI '95*, 1995.

http://staff.psy.gla.ac.uk/~steve/TAU1.html http://www.sigchi.org/bulletin/1996.2/Steve-Draper.html,

Keywords: Human Factors

This documents experiments that were done to see how users adapted to increasing delays between their actions and the computers' responses. The citations give some links into the Human Factors literature on this subject.

(Oculus 2006) Oculus, "GeoTime Visualization for Temporal and Spatial Analysis of Evidence", 2006.

http://www.oculusinfo.com/papers/GeoTime_Brochure_06.pdf

Keywords: Time and Space; Canadian Quality = 0 0 2 1 2

This is the corporate brochure that describes GeoTime, the Oculus product that most directly addresses defence applications.

(Olson et al. 2001) G.M. Olson, T.W. Malone and J.B. Smith, Coordination Theory and Collaboration Technology, Lawrence Erlbaum Associates, 2001.

http://www.amazon.com/gp/product/0805834036/104-0056607-2719103?v=glance&n=283155,

Keywords: Not MISR ; Collaboration

This book deals with the cognitive and collaborative process, not with visualization specifically.

(Pacific Northwest National Laboratory 2006) Pacific Northwest National Laboratory, "Information Visualization", 2006.

http://www.pnl.gov/infoviz/,

Keywords: Centre of Excellence Quality = 1 1 2 1 2

PNNL is the home page for both the National Visual Analysis Center (NVAC) and visualization research projects such as Starlight.

(Palanque 1995) P. Palanque, "Temporal Aspects of Usability: Time Modelling in Petri Nets for the Design of Interactive Systems ", *Proc. CHI '95*, 1995.

http://www.sigchi.org/bulletin/1996.2/Philippe-Palanque.html,

Keywords: Time and Space ; Software Resource

An article describing how to use Petri nets to visualize time.

(PARC 2006) PARC, "Information Visualization & Interaction", 2006.

http://www.parc.xerox.com/research/projects/sensemaking/visualization_interaction/default.html,

Keywords: Human Factors Quality = 0 0 1 1 2

Although PARC initiated many of the fundamental visualization concepts (e.g. the Graphical User Interface) this one-page summary of their current work suggests that they are no longer leaders. Apparently, their research now focused on indexing, navigating, and browsing huge amounts of data, and they did work under ARDA's AQUAINT program. They have an ACH (Analysis of Competing Hypotheses) tool that helps users explicitly capture hypotheses, overcome cognitive biases, and actively search for disconfirming or inconsistent evidence

(Peuquet 2002) D.J. Peuquet, Representations of Space and Time, Guilford Press, 2002.

http://www.amazon.com/gp/product/1572307730/104-0056607-2719103?v=glance&n=283155,

Keywords: Time and Space Quality = 1 2 1 1 1

This book is not primarily about visualizing Time and Space - it has 324 pages, and the explicit discussion of visualization starts on page 288. It does however talk authoritatively about adding a time dimension to Geographic Information Systems (GIS), including data structures etc, and as GIS systems have good visualization capabilities, so it may be relevant as a secondary source.

(Pfitzner et al. 2001) D. Pfitzner, V. Hobbs and D. Powers, "A Unified Taxonomic Framework for Information Visualization ", *Proc. 2nd Australian Institute of Computer Ethics Conference,* Canberra, 2001.

http://citeseer.ist.psu.edu/rd/51278349%2C658804%2C1%2C0.25%2CDownload/http://citeseer.ist.psu.edu/cache/papers/cs/30399/http:zSzzSzcrpit.comzSzconfpaperszSzCRPITV24Pfitzner.pdf/pfitzner01unified.pdf

Keywords: Philosophical

Not sure that this paper is authoritative, but it gives a good stab and providing some structure to the diverse field of information visualization. Useful for checking for obvious things you might have forgotten to think about. It also gives some helpful lists of does and don'ts.

(Pirolli et al. 2005) P. Pirolli and S. Card, "Sensemaking Processes of Intelligence Analysts and Possible Leverage Points as Identified Through Cognitive Task Analysis", *Proc. 2005 International Conference on Intelligence Analysis*, 2005.

https://analysis.mitre.org/proceedings/Final_Papers_Files/206_Camera_Ready_Paper.pdf

Keywords: Requirements; Human Factors

This is a useful analysis of the process by which Intelligence Analysts extract information from data. It will, for example, provide a good starting point for developing MOEs for new visualization strategies.

(Plaisant et al. 1995) C. Plaisant, D. Carr and B. Shneiderman, "Image-browser taxonomy and guidelines for designers" IEEE Software **12**(2): 21-32, 1995.

http://ieeexplore.ieee.org/search/wrapper.jsp?arnumber=368260,

Keywords: Requirements

Introduces a specification technique to describe 2D browsers and a task taxonomy, suggests design features and guidelines, and reviews existing browsers.

(Porathe 2002) T. Porathe, "Real-Time 3D Nautical Navigational Visualisation ", *Proc. Massive Military Data Fusion and Visualisation: Users Talk with Developers,* Halden, Norway, 2002.

http://www.idp.mdh.se/personal/tpe01/publicering/porathelPaperHalden02.pdf

Keywords: Software Resource Quality = 1 1 2 1 1

Paper focusing on challenges associated with on-the-bridge navigation aids, and how visualization tools could help mariners avoid obstacles and other ships.

(PWGSC 2005) PWGSC, "Information Visualization", Solicitation W7707-053019/A, Halifax, September 14, 2005.

Request for proposal for the present study.

(Pylyshyn 2003) Z. Pylyshyn, Seeing and Visualizing: It's not what you think., MIT Press, 2003.

http://www.amazon.com/gp/product/0262162172/104-0056607-2719103?v=glance&n=283155,

Keywords: Philosophical

This book was not reviewed. The book looks at the internal processing of imagery from the eye (pre-cognitive) to the conscious brain. It appears to be rather academic with respect to the task of MISR.

(Qinetiq 2004) Qinetiq, "QinetiQ Demonstrates Autostereo 3D Display Wall ", 2004.

http://www.qinetiq.com/home/newsroom/news_releases_homepage/2004/3rd_quarter/autostereo_3d.html,

http://www.qinetiq.com/home/technologies/technologies/optronics/pad/hpv/3d.Par.0006.File.pdf

Keywords: Display Hardware

Qinetic is marketing this Display Wall to the oil and gas industry. It provides 3D Stereo without special glasses.

(Raskar 2004) R. Raskar, "Projectors: advanced graphics and vision techniques", *Proc. International Conference on Computer Graphics and Interactive Techniques* Los Angeles, CA, 2004.

http://portal.acm.org/citation.cfm?id=1103900.1103923,

Keywords: Display Hardware

This is a course description for using projectors in information visualization.

(Reed et al. 1997) M. Reed and D. Heller, "On-line Library of Information Visualization Environments". University of Maryland research page on Information Visualization, 1997.

http://www.otal.umd.edu/Olive/,

Keywords: Review Article

Rather out-of-date library of visualization research, from Ben Shneiderman's lab.

(Risch 2006) J. Risch, "Starlight - Introduction". 2006.

http://starlight.pnl.gov/introduction.stm,

Keywords: Software Resource; Defence; Visual Analytics Quality = 1 1 2 2 2

This is the main website for Starlight, which is a leading research software environment for information visualization and fusion. The website provides extensive examples of what Starlight does, albeit with few details of the underlying algorithms. A major achievement of Starlight is the definition of schemas that are general enough to allow a wide variety of data to be co-visualized using a finite number of visualization tools.

(Robertson 1998) G. Robertson, "Data Mountain: Using Spatial Memory for Document Management", *Proc. 11th Annual ACM Symposium on User Interface Software and Technology*, p. 153-162, 1998.

http://citeseer.ist.psu.edu/robertson98data.html,

Keywords: Tabular data

This is another specific visualization strategy, this time for viewing many file icons on a sloping plane, with perspective.

(Robertson et al. 2002a) G. Robertson, K. Cameron, M. Czerwinski and D. Robbins, "Animated Visualization of Multiple Intersecting Hierarchies" Journal of Information Visualization **1**(1): 50-65, 2002a.

http://citeseer.ist.psu.edu/robertson02animated.html,

Keywords: Tabular data

This is a specific visualization strategy - this time for visualizing hierarchies when members can belong to many different hierarchies.

(Robertson et al. 2002b) G. Robertson, K. Cameron, M. Czerwinski and D. Robbins, "Polyarchy visualization: visualizing multiple intersecting hierarchies", *Proc. Conference on Human Factors in Computing Systems,* Minneapolis, p. 423-430, 2002b.

http://citeseer.ist.psu.edu/robertson02polyarchy.html,

Keywords: Tabular data

This is an important contribution to a very specific visualization task: visualizing hierarchies.

(Robertson et al. 2005) G. Robertson, M. Czerwinski and J. Churchill, "Visualization of Mappings Between Schemas", *Proc. Conference on Human Factors in Computing Systems*, p. 432-439, 2005.

http://research.microsoft.com/users/marycz/Schemamapper-submitted.pdf

Keywords: Tabular data ; Human Factors

This is another specific visualization strategy for hierarchical and tabular data.

(Robertson et al. 1991) G.G. Robertson, J.D. Mackinlay and Stuart K. Card, "Cone Trees: animated 3D visualizations of hierarchical information", *Proc. SIGCHI conference on Human factors in computing systems: Reaching through technology,* New Orleans, p. 189-194, 1991.

Keywords: Tabular data

Chaomei Chen (Chen 2003) refers to this as one of the most influential articles in the field of information visualization. It was seminal in much later work with cone trees and tree maps, and served as an inspiration that visualizations of hierarchical data could be really useful.

(Rogowitz et al. 1993) B.E. Rogowitz and L.A. Treinish, "An Architecture for Rule-Based Visualization", *Proc. Proceedings of the 4th conference on Visualization '93* San Jose, California p. 236-243, 1993.

http://portal.acm.org/citation.cfm?coll=GUIDE&dl=GUIDE&id=949889,

Keywords: Architecture

Develops an architecture in which descriptors of the data and metadata flow down to constrain the visualization operations.

(Rushmeier et al. 1997) H. Rushmeier, H. Barrett, P. Rheingans, S. Uselton and A. Watson, "Perceptual Measures for Effective Visualizations", *Proc. 8th IEEE Visualization Conference,* Phoenix, p. 515-517, 1997.

http://www.cs.brown.edu/research/vis/docs/pdf/Rushmeier-1997-PME.pdf

Keywords: Review Article

This is an oft-cited seminal paper that asks a lot of questions, and makes some speculations, but gives little in the way of a solution. One suspects that it was an inspiration to many of the current workers.

(Salerno et al. 2004) J. Salerno, M. Hinman and D. Boulware, "Building A Framework For Situation Awareness", *Proc. The 7th International Conference on Information Fusion,* Stockholm, Sweden, 2004.

http://www.fusion2004.foi.se/papers/IF04-0219.pdf

Keywords: MOE

An analysis of what "situational awareness" means, and how it can be measured.

(Saraiya et al. 2005) P. Saraiya, P. Lee and C. North, "Visualization of Graphs with Associated Timeseries Data ", *Proc. IEEE Symposium on Information Visualization* p. 30, 2005.

http://infovis.cs.vt.edu/papers/infovis05-grapheval.pdf

Keywords: Time and Space ; Human Factors

This is a careful study of the problem of co-visualizing time-series data with abstract information spaces, to look for correlations. The application used is mainly in biology, but there are potential overlaps with MISR, where the time-series might be the track of a ship, while the abstract data space might be cargo or personnel characteristics of the ship.

(Seetzen et al. 2004) H. Seetzen, W. Heidrich, W. Stuerzlinger, G. Ward, L. Whitehead, M. Trentacoste, A. Ghosh and A. Vorozcovs, "High Dynamic Range Display Systems" ACM Transactions on Graphics (TOG) **23**(3), 2004.

http://www.cs.ubc.ca/labs/imager/tr/pdf/Seetzen:2004:HDR.pdf,

Keywords: Display Hardware ; Canadian

Description of high dynamic range display solutions from Vancouver. It is not clear that high dynamic range adds value for MISR.

(Shanbhag et al. 2005) P. Shanbhag, P. Rheingans and M. desJardins, "Temporal Visualization of Planning Polygons for Efficient Partitioning of Geo-Spatial Data ", *Proc. IEEE Symposium on Information Visualization*, 2005.

http://maple.cs.umbc.edu/papers/infovis05-shanbhag.pdf

Keywords: Time and Space

This paper begins with a discussion of how non-geographic attributes can be coded into a geographic scene. It then treats temporal data (specifically the change in one of the attributes) as a new attribute, and demonstrates ways to display it in the scene.

(Shneiderman 1996) B. Shneiderman, "The Eyes Have It: A Task by Data Type Taxonomy for Information Visualizations ", *Proc. 1996 IEEE Symposium on Visual Languages*, p. 336-343, 1996.

http://citeseer.ist.psu.edu/shneiderman96eyes.html,

(Shneiderman 2006) B. Shneiderman, *Curriculum Vitae*, University of Maryland, online C.V. Accessed 2006.

http://www.cs.umd.edu/~ben/,

Keywords: Research Leader

Ben Shneiderman is a Professor in the Department of Computer Science, University of Maryland, College Park. He is Founding Director (1983-2000) of the Human-Computer Interaction Laboratory, and Member of the Institute for Advanced Computer Studies and the Institute for Systems Research at UMCP. Dr. Shneiderman is the author of Software Psychology: Human Factors in Computer and Information Systems (1980). In 1999 he co-authored Readings in Information Visualization: Using Vision to Think with Stu Card and Jock Mackinlay, then in 2003 continued in this direction by co-authoring The Craft of Information Visualization: Readings and Reflections with Ben Bederson. He is an advisor for treemap supplier HiveGroup and for ClockWise3D, as well as a member of the Technical Advisory Board for ILOG.

(Shuping et al. 2004) D. Shuping and W. Wright, "GeoTime Visualization of RFID Providing Global Visibility of the DoD Supply Chain". RFID Exchange 2004.

http://www.rfidexchange.com/downloadfiles/geotimeRFID.doc,

Keywords: Time and Space

This is an aggressive attempt to co-visualize space and time events for military applications, and hence is very relevant to MISR. The paper has clear graphics explaining the problems being addressed.

(SLIS 2006) SLIS, " InfoVis Cyberinfrastructure – Software", 2006.

http://iv.slis.indiana.edu/sw/index.html,

Keywords: Review Article Quality = 1 2 1 1 1

This page provides links to various Information Visualization resources and projects on the Internet.

(Smallman et al. 2001) H. Smallman, M.S. John, H. Oonk and M. Cowen, "SYMBICONS: A Hybrid Symbology That Combines the Best Elements of SYMBOLS and ICONS", *Proc. 45th Annual Meeting of the Human Factors and Ergonomics Socierty*, p. 114-119, 2001.

http://www.pacific-science.com/pvt/Symbicons%20HFES.pdf

Keywords: Software Resource ; Human Factors

Describes how "Symbicons" (combination of symbols and icons) can be more effective than either symbols or icons.

(Spence 2000) R. Spence, Information Visualization, ACM Press, 2000.

http://www.amazon.com/gp/product/0201596261/104-0056607-2719103?v=glance&n=283155,

Keywords: Textbook

This book was not reviewed in this project.

(Stolte et al. 2002) C. Stolte, D. Tang and P. Hanrahan, "Polaris: A System for Query, Analysis, and Visualization of Multidimensional Relational Databases" IEEE Transactions on Visualization and Computer Graphics **8**(1), 2002.

http://graphics.stanford.edu/papers/polaris_extended/,

http://graphics.stanford.edu/papers/polaris_extended/polaris.pdf

Keywords: Tabular data

One of many table-based visualization tools. Illustrates that this visualization task is over-subscribed.

(Stone et al. 2005) D. Stone, C. Jarrett and M. Woodroffe, User Interface Design and Evaluation, Morgan Kaufmann, 2005.

http://www.amazon.ca/exec/obidos/ASIN/0120884364/qid=1150835723/sr=8-5/ref=sr_8_xs_ap_i5_xgl14/701-7652254-9270728,

Keywords: Human Factors

Not Reviewed

(Swindells et al. 2004) C. Swindells, B.A. Po, I. Hajshirmohammadi, B. Corrie, J. Dill, B.D. Fisher and K.S. Booth, "Comparing CAVE, Wall, and Desktop Displays for Navigation and Wayfinding in Complex 3D Models", *Proc. Computer Graphics International*, p. 420-427, 2004.

http://www.cs.ubc.ca/labs/imager/tr/pdf/po2004c.pdf

Keywords: Display Hardware ; Canadian

Human factors study of three display approaches.

(Taylor 2002) M. Taylor, "The VisTG Model for Visualisation", *Proc. Massive Military Data Fusion and Visualisation: Users Talk with Developers*, Halden, Norway, 2002.

http://vistg.net/Halden/presentations/Session%202/MMTHALDE.PPT,

Keywords: Requirements ; Time and Space

PowerPoint slides presenting ideas on what should be in good visualizations. Rather esoteric and philosophical; lacking in solid content.

(Taylor 2006) M.M. Taylor, "Guidelines for Evaluating Visualisation System Designs and Specifications". 2006.

http://www.vistg.net/documents/Working%20Papers/guidelines/guidelines.html,

Keywords: MOE ; Human Factors

Though not authoritative (lacks references, not peer reviewed, refers to itself as a "working paper") this is a very accessible site that may be useful as a sanity check when developing a new visualization, or as a guide for establishing Measures of Effectiveness.

(Terrenghi et al. 2006) L. Terrenghi, R. May and P. Baudisch. Information Visualization and Interaction Techniques for Collaboration across Multiple Displays Montreal, 2006.

http://nvac.pnl.gov/ivitcmd_chi06/,

Keywords: Display Hardware

This is a very current conference specifically looking at the usefulness of various display technologies: form factors, size, dimensionality, etc.

(Thomas 2005) J. Thomas, "Visual Analytics: a Grand Challenge in Science - Turning Information Overload into the Opportunity of the Decade", *Proc. Information Visualization*, 2005.

http://csdl.computer.org/comp/proceedings/infovis/2005/2790/00/2790vii.pdf

This is the leading journal in Information Visualization

(Thomas et al. 1999) J. Thomas, K. Cook, V. Crow, B. Hetzler, R. May, D. McQuerry, R. McVeety, N. Miller, G. Nakamura, L. Nowell, P. Whitney and P.C. Wong, "Human Computer Interaction with Global Information Spaces – Beyond Data Mining". 1999.

http://www.pnl.gov/infoviz/hci_gis.pdf

Keywords: Visual Analytics

This is a paper on what needs to be achieved in visualizing the big picture. The application examples that it gives are not from MISR but the vision speaks to the need for a broader view of the emerging and evolving maritime picture.

(Thomas 2006) J.J. Thomas, *Curriculum Vitae*, National Visualization and Analytics Center, online C.V. Accessed 2006.

http://nvac.pnl.gov/leadership.stm,

Keywords: Research Leader

Jim Thomas is the head of the National Visualization and Analytics Center (NVAC) in Richland Washington.

(Thomas et al. 2005) J.J. Thomas and K.A. Cook, Illuminating the Path, Richland, Washington, National Visualization and Analytics Center, 2005.

http://nvac.pnl.gov/agenda.stm

Keywords: Visual Analytics Quality = 2 2 2 2 2

This is the key document for Visual Analytics (i.e. the interactive use of computer visualization tool to extend humans' inherent analytical tools) and to some extent for defence applications of visualization tools in general.

(Thomson 2005) Thomson, "EndNote software v. 9.0.1". 2005.

www.endnote.com,

Home page for the EndNote software, which was used to organize and print out the references in this annotated bibliography.

(Thomson et al. 2005) J. Thomson, B. Hetzler, A. MacEachren, M. Gahegan and M. Pavel, "A Typology for Visualizing Uncertainty", *Proc. Conference on Visualization and Data Analysis* San Jose, 2005

http://www.geovista.psu.edu/publications/2004/Thomson_VDA205_prepub_draft_july5.pdf

Keywords: Uncertainty

Unfortunately does not live up to its abstract - the promised typology never really happens. There is a typology of different kinds of error in geospatial data.

(Tory et al. 2006) M. Tory, A.E. Kirkpatrick, M.S. Atkins and T. Möller, "Visualization Task Performance with 2D, 3D, and Combination Displays " IEEE Transactions on Visualization and Computer Graphics **12**(1): 2-13, 2006.

http://doi.ieeecomputersociety.org/10.1109/TVCG.2006.17,

Keywords: Display Hardware

(Tory et al. 2004a) M. Tory and T. Moller, "Human Factors in Visualization Research " IEEE Transactions on Visualization and Computer Graphics **10**(1): 72-84, 2004a.

http://doi.ieeecomputersociety.org/10.1109/TVCG.2004.1260759,

Keywords: Review Article

(Tory et al. 2004b) M. Tory and T. Moller, "Rethinking Visualization: A High-Level Taxonomy ", *Proc. IEEE Symposium on Information Visualization*, p. 151-158, 2004b.

http://www.cs.sfu.ca/~torsten/Publications/Papers/infovis04.pdf

Keywords: Philosophical ; Canadian

Taxonomies are useful when they clarify the underlying structure of a field of endeavour. The taxonomy proposed here does not achieve that, and thus is not very helpful.

(Tufte 1997a) E. Tufte, Visual Explanations: Images and Quantities, Evidence and Narrative Graphics Press 1997a.

http://www.edwardtufte.com/tufte/books_visex,

Keywords: Time and Space; Philosophical; Graphics Quality = 1 1 2 2 2

Tufte moves from space to space-time, looking at ways to visualize change and cause-and-effect.

(Tufte 2006) E. Tufte, Beautiful Evidence, Graphics Press, 2006.

http://www.edwardtufte.com/tufte/books_be,

Keywords: Philosophical Quality =? ? 2 2 2

This book was announced but not yet available when this report was issued. It is about "how 'seeing' turns into 'showing,' how empirical observations turn into explanations and evidence presentations." Chapter 5 is entitled "The Fundamental Principles of Analytical Design."

(Tufte 1983) E.R. Tufte, The Visual Display of Quantitative Information, Graphics Press, 1983.

http://www.amazon.com/gp/product/096139210X/104-0056607-2719103?v=glance&n=283155,

Keywords: Graphics Quality = 1 0 2 2 2

This is a small but seminal text in defining "graphical excellence" and it is widely cited in the literature. It constrains itself to static two-dimensional presentations of quantitative information.

(Tufte 1990) E.R. Tufte, Envisioning Information, Graphics Press, 1990.

http://www.amazon.com/gp/product/0961392118/104-0056607-2719103?v=glance&n=283155,

Keywords: Graphics

Tufte extends his earlier seminal work on graphical design toward more challenging multivariate visualization problems - what he calls "escaping flatland". More philosophical than most texts on graphics.

(Tufte 1997b) E.R. Tufte, Visual and Statistical Thinking: Displays of Evidence for Making Decisions, Graphics Press, 1997b.

http://www.amazon.com/gp/product/0961392134/104-0056607-2719103?v=glance&n=283155,

Keywords: Philosophical Quality = 1 ? 1 2 2

Case studies of how the clarity of information visualization can influence history. As with Tufte's other books, this is philosophical, opinionated, and inspirational. This is similar to (perhaps identical to) Chapter 2 of Tufte's Visual Explanations book.

(Tufte 2003) E.R. Tufte, The Cognitive Style of PowerPoint, Graphics Press, 2003.

http://www.amazon.com/gp/product/0961392150/104-0056607-2719103?v=glance&n=283155,

Keywords: Philosophical

Anti-Powerpoint polemic.

(Tversky et al. 2002) B. Tversky, J.B. Morrison and M. Betrancourt, "Animation: Can it Facilitate" International Journal of Human Computer Studies **57**: 247-262, 2002.

http://serc.carleton.edu/files/NAGTWorkshops/visualize04/Tversky_2002.pdf

Keywords: Human Factors

This is a technical discussion of whether animations are helpful for visualization, or not. The conclusion is that they may be useful for schematic elements (e.g. animated icons) to draw and direct attention. The article concludes that using animation to convey subtle information is not likely to be any more effective than "clever" static diagrams.

(UNH 2006) UNH, "Data Visualization Lab People". University of New Hampshire, 2006.

http://www.ccom.unh.edu/vislab/CWBio.html,

Website for the visualization lab at the University of New Hampshire

(US Army 2006) US Army, "Joint Mapping Tool Kit (JMTK)", 2006.

http://www.erdc.usace.army.mil/pls/erdcpub/!www_fact_sheet.product_page?ps_product_numb=49798&tmp_Main_Topic=&page=PROBLEM&page=DOCS#DOCS,

Keywords: Software Resource

This is primarily a GIS resource toolkit.

(van Dorp et al. 2002) J.R. van Dorp, J.R.W. Merrick, J. Harrald, T. Mazzuchi and M. Grabowski., "Assessing Uncertainty in Simulation Based Maritime Risk Assessment". 2002.

http://www.seas.gwu.edu/~dorpjr/Publications/TechnicalReports/NSFProject/SFBayesianSimulation.pdf,

Keywords: Uncertainty

This is a careful discussion of statistical modelling issues for assessing risk from the uncertainty in ship tracks. The application is focused on a littoral site (San Francisco Bay) but the techniques are generally relevant. It is a good illustration of the use of Percentil Maps for visualizing uncertainty. There is a good bibliography.

(vanDam 2001) A. vanDam, "User Interfaces: Disappearing, Dissolving and Evolving" Communication of the ACM **44**(3): 50-52, 2001.

http://lair.indiana.edu/courses/l578/papers/vandam.pdf

Keywords: Philosophical Quality = 1 0 1 2 1

This is a short, informal, opinion piece envisioning a future where user interfaces come off the computer screen. Like Neuromancer (Gibson, 1984) it adds value by encouraging a wider set of possible solutions. It suggests, for example, that user interfaces should detect and adapt to the aptitudes and preferences of individual operators.

(vanDam et al. 1999) A. vanDam, V. Abrash, O. Bernsen, T. Furness, B. Herzog, T. Kunii, B. Shneiderman, M. Turk and T. Whitted, "Report of the Working Group on Foundations of Future Interfaces: Devices, Hardware and Software", *Proc. International Conference on Computer Graphics and Interactive Techniques*, p. 49-54, 1999.

http://www.eimc.brad.ac.uk/news/7.htm http://www.eimc.brad.ac.uk/news/7_2.htm,

Keywords: Requirements; Display Hardware Quality = 1 0 1 1 2

These links provide a rather hastily-assembled outline of where display technology and visualization strategies will go, and need to go, in the future. It is very readable and interesting.

(W.R. Systems 2006) W.R. Systems, "Data Analysis and Visualization Solutions", 2006.

http://www.wrsystems.com/datavisualization.asp,

Keywords: Software Resource

Although this website name suggests that it is about visualization, it is more accurately identified as a site about 3D immersive simulation capabilities.

(Ward 1994) M.O. Ward, "XmdvTool: Integrating Multiple Methods for Visualizing Multivariate Data", *Proc. IEEE Conference on Visualization (VIS 94)*, p. 326-333, 1994.

http://portal.acm.org/citation.cfm?id=951146&dl=GUIDE&coll=GUIDE,

Keywords: Software Resource

This describes a specific software tool for projecting multivariate data onto a two-dimensional screen.

(Ware 2003) C. Ware, "Thinking with Visualization", *Proc. IEEE Symposium on Information Visualization* 2003.

http://csdl2.computer.org/comp/proceedings/infovis/2003/2055/00/20550001.pdf

Keywords: Human Factors

(Ware 2004) C. Ware, Information Visualization: Perception for Design, Morgan Kauffmann, 2004.

http://www.amazon.com/gp/product/1558608192/104-0056607-2719103?v=glance&n=283155,

Keywords: Textbook ; Human Factors Quality = 2 2 2 2 2

This is the definitive reference book on Human Factors for visualization. Colin Ware is recognized as an international authority on the subject. The book is well organized, thoroughly illustrated, and easily browsed. It is useful both as a stand-alone reference and as a pointer to the wider literature.

(Ware 2006) C. Ware, *Curriculum Vitae*, University of New Hampshire, online C.V. Accessed 2006.

http://www.ccom.unh.edu/vislab/CWBio.html,

Keywords: Research Leader

Director of the Data Visualization Research Lab at the University of New Hampshire, and author of a core reference in Human Factors for visualization. He is active in both human factors and applied visualizations.

(Ware et al. 1999) C. Ware and J. Rose, "Rotating Virtual Objects with Real Handles" ACM Transactions on CHI **6**(2): 162-180, 1999.

http://www.ccom.unh.edu/vislab/PDFs/Rotation.pdf

Keywords: Human Factors

This article asks whether Haptic (touch) feedback will allow faster manipulation of 3D objects. It concludes that, if the haptic feedback is fast enough, it can dramatically speed up interactions with a 3D environment.

(Westgrid 2006) Westgrid, "WestGrid Collaboration & Visualization ", 2006.

http://www.westgrid.ca/collabvis/,

Keywords: Centre of Excellence ; Canadian

Westgrid is a collaboration between eight Western Canadian research institutions to provide an advanced collaboration and visualization infrastructure for visualization development.

(Wickens 2005) C.D. Wickens, "Visualizing Uncertainty in High Time-Stress". 2005.

http://www7.nationalacademies.org/bms/Chris_Wickens_PP.ppt,

Keywords: Uncertainty ; Human Factors

This is a relatively low-quality PowerPoint presentation that reiterates how more research needs to be done about whether their is added value in representing uncertainty to a user. The focus is on users under short time-fuses, especially air pilots. It has a one-page bibliography.

(Wikipedia 2006) Wikipedia, "Scientific visualization", Accessed 2006.

http://en.wikipedia.org/wiki/Information_visualization,

Keywords: Review Article Quality = 1 1 0 1 0

This is a helpful introduction to the research fields and research community in scientific visualization. It provides a brief statement of what the different branches of the field are, and links to some other pages. The list of leading researchers that it gives is not comprehensive.

(Wilkinson 1999) L. Wilkinson, The Grammar of Graphics, Springler Verlag, 1999.

http://www.spss.com/research/wilkinson/TheGrammarOfGraphics/GOG.html,

Keywords: Graphics

This book was not reviewed. The publisher says it: "presents a unique foundation for producing almost every quantitative graphic found in scientific journals, newspapers, statistical packages, and data visualization systems."

(Wilkinson et al. 2005) L. Wilkinson, A. Anand and R. Grossman, "Graph-Theoretic Scagnostics", *Proc. IEEE Symposium on Information Visualization*, p. 21, 2005.

http://www.rgrossman.com/dl/proc-094.pdf

Keywords: Visual Analytics; Software Resource Quality = 2 2 1 2 1

This describes ways to classify characteristics of scatterplots, which are a leading tool for visualizing patterns in generic multi-dimensional data, and thus provides a good foundation for understanding them.

(Wise et al. 1995) J. Wise, J. Thomas, K. Pennock, D. Lantrip, M. Pottier, A. Schur and V. Crow, "Visualizing the non-visual: Spatial analysis and interaction with information from text documents", *Proc. Information Visualization*, p. 51-58, 1995.

http://www.cs.duke.edu/courses/spring03/cps296.8/papers/vis_non_visual.pdf

Keywords: Tabular data

Presents a way to visualize and browse textual content using "galaxies" of stars.

(Wittenbrink et al. 1996) C.M. Wittenbrink, A.T. Pang and S.K. Lodha, "Verity Visualization: Visual Mappings", UCSC-CRL-95-48, 1996.

http://www.cse.ucsc.edu/research/slvg/verity.html,

Keywords: Uncertainty

The methods discussed here for the most part are not helpful for Maritime ISR, but this is one of the few papers that discusses the visualization of uncertainty. There are a few images at the end that show how to visualize uncertainty in time track data, but I wouldn't use them for MISR.

(Wong et al. 2003) N. Wong, S. Carpendale and S. Greenberg, "EdgeLens: An Interactive Method for Managing Edge Congestion in Graphs", *Proc. IEEE Symposium on Information Visualization* p. 7, 2003.

http://pages.cpsc.ucalgary.ca/~sheelagh/personal/pubs/2003/wong-carp-infovis03-submit.pdf

Keywords: Software Resource ; Canadian Quality = 1 1 1 2 1

Description of a specific visualization tool, in this case a mathemical method for de-cluttering screens that have a lot of nodes connected by lines.

(Woods et al. 2002) D.D. Woods, E.S. Patterson, E.M. Roth and K. Christoffersen, "Can We Ever Escape From Data Overload?" Cognition, Technology & Work **4**: 22-36, 2002.

http://citeseer.ist.psu.edu/woods02can.html,

Keywords: Overload

Woods proposes that Data Overload is best addressed by providing people with efficient ways to remove clutter (insignificant data) in a context-sensitive manner. Interestingly, he starts out by contrasting this with two "standard" approaches: reducing the amount of data or expanding the workforce. The challenge, of course, is to do this in a context-sensitive way, and in the end he gives no radical solutions.

(Wright et al. 2002a) W. Wright and P. Clarke, "Visualization Techniques for Intrusion Detection", *Proc. Workshop on Statistical and Machine Learning Techniques in Computer Intrusion Detection,* Johns Hopkins University, 2002a.

Keywords: Not MISR

(Wright et al. 2002b) W. Wright and T. Kapler, "Visualization of Blue Forces Using Blobology", *Proc. Command and Control Research and Technology Symposium*,, 2002b.

http://www.dodccrp.org/events/2002/CCRTS_Monterey/Tracks/pdf/029.PDF

Keywords: Time and Space ; Coverage maps; Defence Quality = 2 1 2 2 2

This is a report of research done under DARPA's Command Post of the Future (CPOF) funding, with extensive consultations with subject matter experts in the US DoD. It looks at using time-varying red and blue blobs overlaid on terrain visualizations to indicate weapon range and strength. The paper is also valuable because of its description of how to collaborate with active forces in the development of viisualization techniques.

(Wright et al. 2005) W.D. Wright, D. Schroh, P. Proulx, B. Cort and D. Jonker, "Advances in nSpace-The Sandbox for Analysis". 2005.

https://analysis.mitre.org/proceedings/Final_Papers_Files/23_Camera_Ready_Paper.pdf

Keywords: Software Resource ; Visual Analytics

This is another report from the company that developed GeoTime software, focused now on providing an interactive workspace (like a landscape) for thinking about what things mean.

(Yamamoto et al. 2006) A. Yamamoto, S. Nagasawa, H. Yamamoto and T. Higuchi, "Electrostatic Tactile Display with Thin Film Slider and Its Application to Tactile Telepresentation Systems " IEEE Transactions on Visualization and Computer Graphics **12**(2): 168-177, 2006.

http://doi.ieeecomputersociety.org/10.1109/TVCG.2006.28,

Keywords: Display Hardware

This is a description of development of a tactile display that communicates by "touch."

(Yu et al. 2004) L. Yu and T.E. Boult, "Understanding Images of Graphical User Interfaces: A New Approach to Activity Recognition for Visual Surveillance ", *Proc. Computer Vision and Pattern Recognition Workshop*, p. 113, 2004.

http://vast.uccs.edu/~tboult/PAPERS/ACM-UIST03-UIGUI-Li-Boult.pdf,

Keywords: Visual Analytics

This describes using visualization tools to interactively define "events that are of interest" for an automated tracking system. The application is thus very relevant to MISR, but the actual incremental contribution is only moderate.

(Zhao et al. 2005) S. Zhao, M.J. McGuffin and M.H. Chignell, "Elastic Hierarchies: Combining Treemaps and Node-Link Diagrams ", *Proc. IEEE Symposium on Information Visualization* 2005.

http://doi.ieeecomputersociety.org/10.1109/INFOVIS.2005.12,

http://www.dgp.toronto.edu/~sszhao/EH_InfoVis_Final.PPT

Keywords: Tabular data ; Software Resource

Proposes a new visualization called "Elastic Hierarchy" that combines advantages of tree maps and node-link diagrams. The paper includes a useful discussion of strengths and weaknesses of various ways to visualize hierarchies.

(Zhou 1999) M. Zhou, "Visual Planning: A Practical Approach to Automated Visual Presentation", *Proc. Sixteeth International Joint Conference on Artificial Intelligence,* Stockholm, p. 634-641, 1999.

(Zhou 2006) M. Zhou, *Curriculum Vitae*, IBM, online C.V. Accessed 2006.

http://researchweb.watson.ibm.com/RIA/People/Zhou/Zhou.htm,

Keywords: Research Leader

Zhou's research interests are some distance from MISR, but she is a recognized leader in visualization.

(Zhou et al. 1996) M. Zhou and S. Feiner, "Data Characterization for Automatically Visualizing Heterogeneous Information", *Proc. 1996 IEEE Symposium on Information Visualization*, p. 13-20, 1996.

Keywords: Software Resource

Focus is on visualizing clinical information which reduces the importance for MISR. Note however the analysis of temporal reasoning.

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(U) This Final Report provides an analysis of the current state of the art for Information Visualization, as it applies to Maritime Intelligence, Surveillance, and Reconnaissance (MISR). It comprises a Literature Survey, an Annotated Bibliography, a Product Review, and recommendations for further research. The Literature Survey focuses on visualization algorithms and strategies, human factors for visualization, and emerging display hardware, and includes a list of foundational books and papers, an introduction to major research leaders, and a list of current pressing research questions. The Annotated Bibliography provides about 240 references to texts, conferences, journals, and institutional websites. The Product Review gives one−page descriptions of sixty eight MISR−related visualization products, ranging from public−domain code for a specific visualization task, to commercial multipurpose toolkits. The report concludes by recommending specific research tasks for visualizing sensor coverage and ignorance, ship tracks in time and space, ship tracks versus “normal” tracks, and attribute data such as cargo and crew.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (Technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus, e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

(U) Information Visualization; Visualization; Maritime Domain Awareness; MDA; Recognized Maritime Picture; RMP; information management; maritime security; maritime picture; domain awareness; product review; literature survey; Infoviz

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